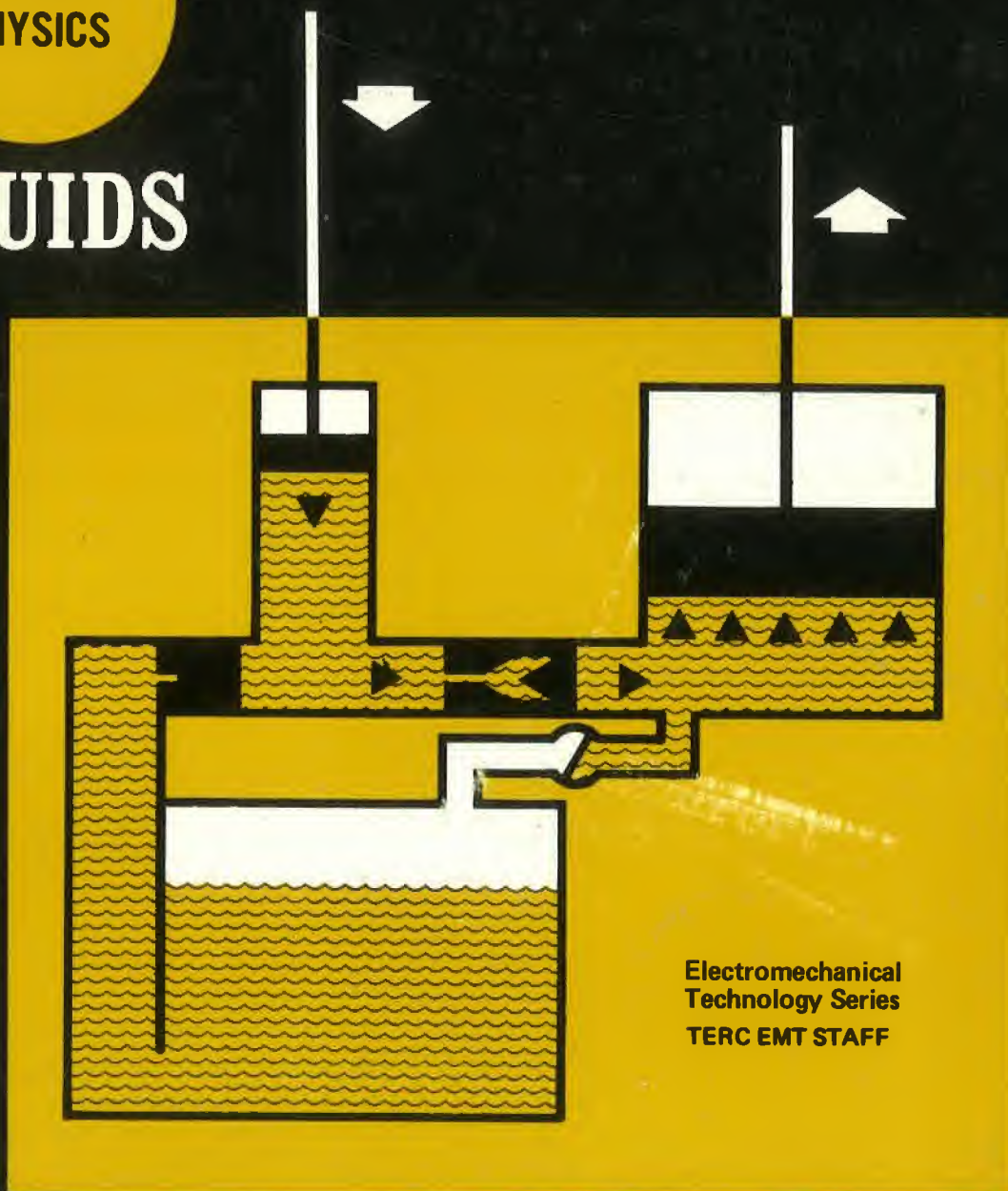


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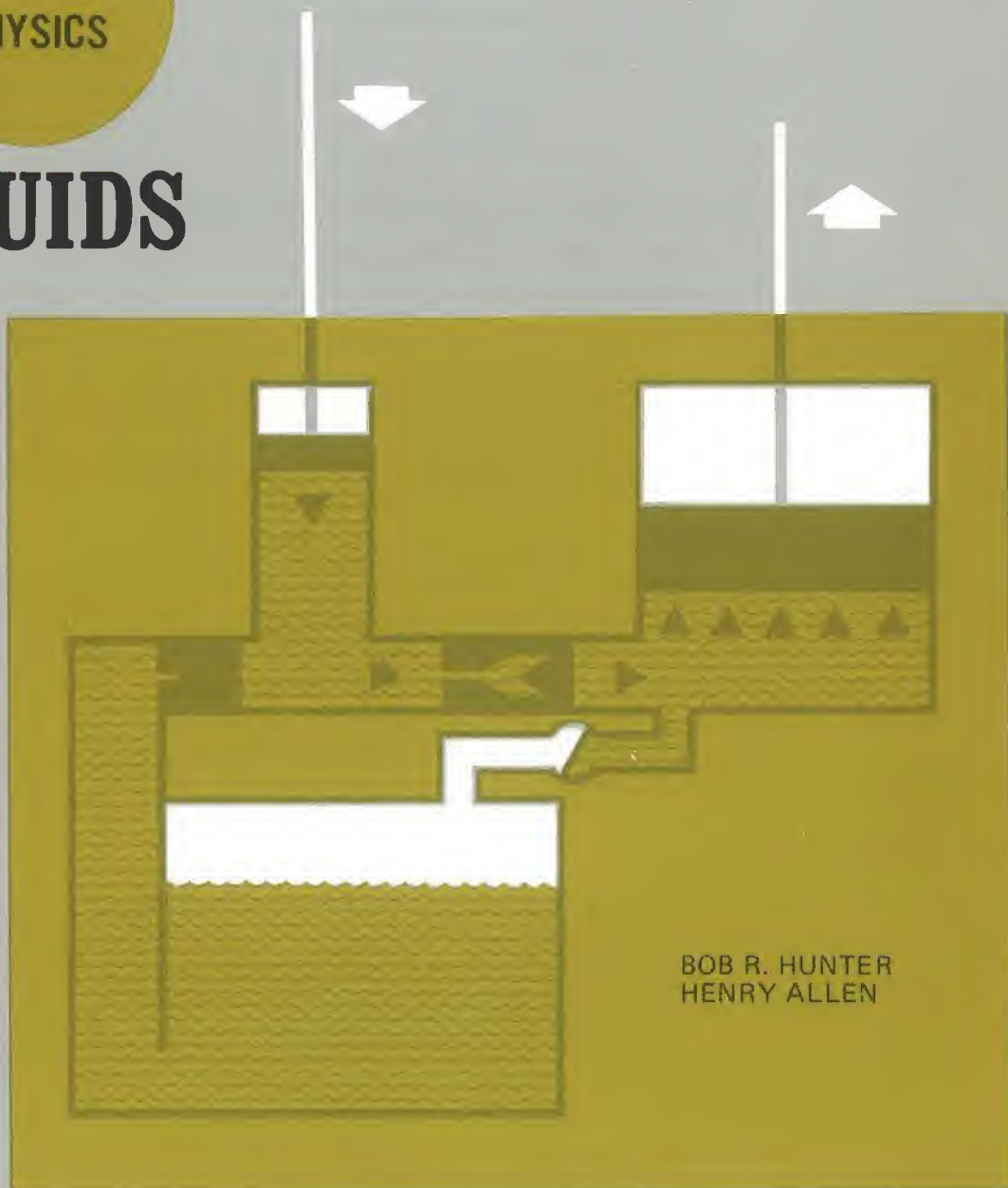


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PHYSICS

FLUIDS



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Foreword

The marriage of electronics and technology is creating new demands for technical personnel in today's industries. New occupations have emerged with combination skill requirements well beyond the capability of many technical specialists. Increasingly, technicians who work with systems and devices of many kinds — mechanical, hydraulic, pneumatic, thermal, and optical — must be competent also in electronics. This need for combination skills is especially significant for the youngster who is preparing for a career in industrial technology.

This manual is one of a series of closely related publications designed for students who want the broadest possible introduction to technical occupations. The most effective use of these manuals is as combination textbook-laboratory guides for a full-time, post-secondary school study program that provides parallel and concurrent courses in electronics, mechanics, physics, mathematics, technical writing, and electromechanical applications.

A unique feature of the manuals in this series is the close correlation of technical laboratory study with mathematics and physics concepts. Each topic is studied by use of practical examples using modern industrial applications. The reinforcement obtained from multiple applications of the concepts has been shown to be extremely effective, especially for students with widely diverse educational backgrounds. Experience has shown that typical junior college or technical school students can make satisfactory progress in a well-coordinated program using these manuals as the primary instructional material.

School administrators will be interested in the potential of these manuals to support a common first-year core of studies for two-year programs in such fields as: instrumentation, automation, mechanical design, or quality assurance. This form of *technical core* program has the advantage of reducing instructional costs without the corresponding decrease in holding power so frequently found in general core programs.

This manual, along with the others in the series, is the result of six years of research and development by the *Technical Education Research Center, Inc.*, (TERC), a national nonprofit, public service corporation with headquarters in Cambridge, Massachusetts. It has undergone a number of revisions as a direct result of experience gained with students in technical schools and community colleges throughout the country.

Maurice W. Roney

The Electromechanical Series

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The three most common means of transporting energy from place to place are through mechanical drives, electrical circuits and fluid systems. Fluids, then, hold a very important position in modern technology. Consequently, the well-prepared technician should be acquainted with the principles of fluid circuits.

Unified Physics/Fluids provides an introductory treatment of basic fluid principles as well as other selected topics. The materials are organized around a number of fundamental concepts of modern technology: differential forces, flow rates, opposition to flow, energy storage, time constants, impedance matching and resonance. The purpose of this organization is to provide a foundation for the study of several related technologies.

The sequence of presentation chosen is not completely inflexible. It is expected that individual instructors may choose to use the materials with some variation from the given sequence. The particular topics chosen for inclusion in this volume were selected primarily for convenience and economy of materials.

The instructional material is presented in an action-oriented format combining many of the features normally found in a textbook with those usually associated with a laboratory manual. Each experiment contains:

1. An INTRODUCTION which identifies the topic to be examined and often includes a rationale for doing the exercise.
2. A DISCUSSION which presents the background, theory, or techniques needed to carry out the exercise.
3. A MATERIALS list which identifies all of the items needed in the laboratory experiment. (Items usually supplied by the student such as pencil and paper are not included in the lists.)
4. A PROCEDURE which presents step-by-step instructions for performing the experiment. In most instances, the measurements are done before calculations so that all of the students can at least finish making the measurements before the laboratory period ends.
5. An ANALYSIS GUIDE which offers suggestions as to how the student might approach interpretation of the data in order to draw conclusions from it.
6. PROBLEMS are often included for the purpose of reviewing and reinforcing the points covered in the exercise. These problems may be of the numerical solution type or simply questions about the exercise.

Students should be encouraged to study the text material, perform the experiment, work included review problems, and submit a technical report on each topic. Following this pattern, the student can acquire an understanding of the principles of modern technology that will be very valuable in the study of specialty subjects and on the job. For best results, these students should be concurrently enrolled in other technical specialty courses and in technical mathematics (algebra and trigonometry).

This material on fluid principles comprises one of a series of volumes prepared for technical students by the TERC EMT staff at Oklahoma State University, under the direction of D.S. Phillips and R.W. Tinnell. The principal authors of these materials were Bob R. Hunter and Henry Allen.

An *Instructor's Data Guide* is available for use with this volume. Mr. Henry Allen was responsible for testing the materials and compiling the instructor's data book for them. Other members of the TERC staff made valuable contributions in the form of criticisms, corrections and suggestions.

It is sincerely hoped that this volume as well as the other volumes in the series, the instructor's data books, and the other supplementary materials will make the study of technology interesting and rewarding for both students and teachers.

THE TERC EMT STAFF

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TO THE STUDENT

Duplicate data sheets for each experiment are provided in the back of the book. These are perforated to be removed and completed while performing each experiment. They may then be submitted with the experiment analysis for your instructor's examination.

experiment 1 REAL OPPOSITION TO FLUID FLOW

INTRODUCTION. Fluid power systems are widely used in industry to perform hundreds of important tasks. These systems inevitably involve resistance to fluid flow. The objective of this experiment is to define and examine resistance as it applies to fluid systems.

DISCUSSION. Resistance or *opposition* to motion or flow, though possibly unfamiliar to us, is something with which we come in contact everyday. When a force acts to change motion or flow, there is often present a force that opposes the original force and limits the change of motion. This opposing action occurs in many physical processes and goes by several different names. *Friction* is the name used in mechanical motions while in electrical circuits, it is called *resistance*. With magnetic circuits, the term *reluctance* is used and *thermal resistance* is used to account for the process that limits heat flow in thermal systems. Since this experiment deals with fluids, we will be directly concerned with the opposition to fluid flow or *fluid resistance*.

Besides limiting change of motion or flow, opposition in many cases results in a transformation of energy, generally into thermal energy. For example, if we were to drag a

brick steadily along a sidewalk, all of the energy we expend is lost in overcoming the friction between the sidewalk and the brick. Since energy cannot be created or destroyed, the energy we expend must have gone somewhere, and it appears as thermal energy. We can feel the temperature rise in energy dissipation by friction by simply rubbing our hands together. In many processes, opposition is characterized by a transformation of energy into thermal energy.

This experiment deals with fluid resistance in a fluid circuit. Fluid circuits may be of two basic types which will affect the resistance of the circuit. In figure 1-1 we see a *series* circuit. All the fluid being pumped from the tank must pass first through motor A, and then through motor B. Whenever all of the fluid passes through each of the components in a system, the components are said to be in *series*.

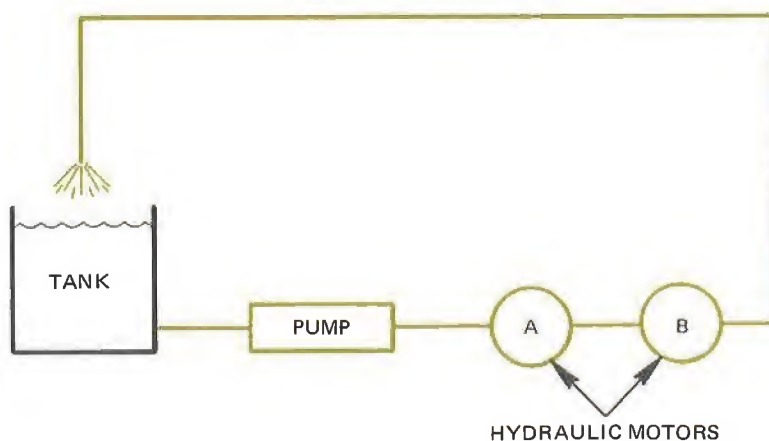


Fig. 1-1 Series Fluid Circuit

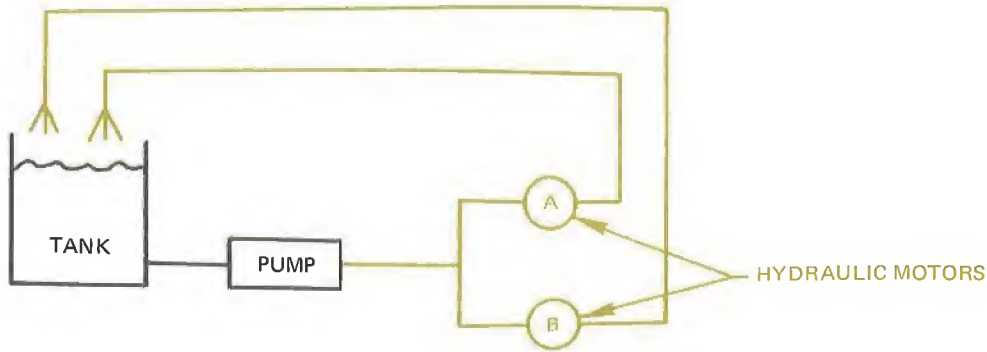


Fig. 1-2 Parallel Fluid Circuit

Figure 1-2 is known as a *parallel* fluid system. In this system the fluid being pumped is divided so that only part of it passes through motor A and part through motor B. Components placed like A and B are said to be in parallel.

As with electronics, man has created symbolic notation to aid in understanding fluid

systems. Circuit drawings are greatly simplified by the use of schematic symbols. A student of fluid systems must learn to identify these symbols in order to read fluid system diagrams. The American Standard symbols in figure 1-3. will be used in this experiment. For a more complete list of American Standard fluid symbols see Appendix.



QUICK DISCONNECT SINGLE CHECK VALVE



DISCONNECT DOUBLE CHECK VALVE



RESERVOIR BELOW FLUID LEVEL
CONNECTING LINE



RESERVOIR ABOVE FLUID LEVEL
CONNECTING LINE



FILTER STRAINER

Fig. 1-3 American Standard Fluid Symbols

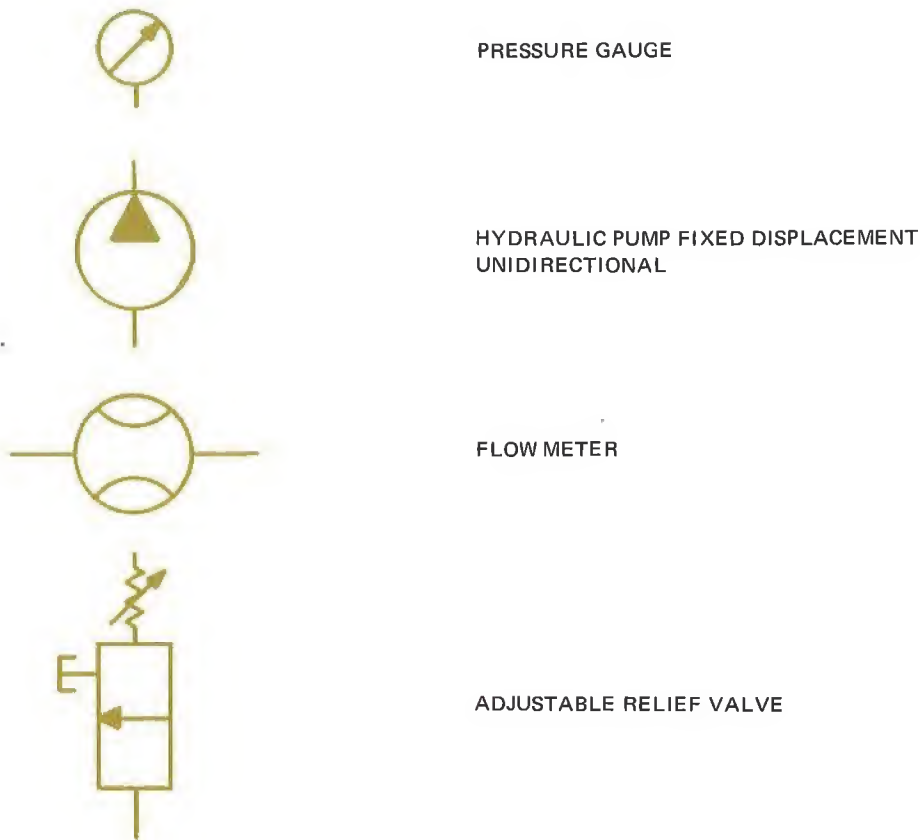


Fig. 1-3 American Standard Fluid Symbols (Continued)

MATERIALS

- 1 Hydraulic bench including pump, relief valve, and reservoir
- 1 $\frac{1}{4}$ " ID plastic hydraulic hose 25 ft long
- 1 $\frac{1}{4}$ " ID plastic hydraulic hose 1 ft long
- 1 $\frac{1}{4}$ " ID plastic hydraulic return hose
- 8 Quick disconnect coupler (male and female)
- 2 Pressure gauges
- 2 Flow meters
- 1 Check valve
- 1 Relief valve

PROCEDURE

1. Construct the hydraulic circuit shown in figure 1-4.

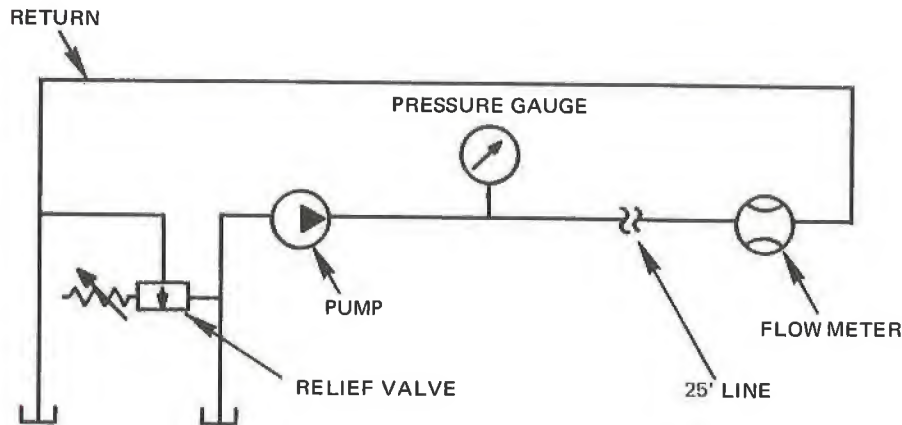


Fig. 1-4 The Experimental Circuit

2. Adjust the relief valve so that the pressure gauge reads 90 psi and record the flow in the data table.
3. Replace the 25-ft hose with a one-foot hose. Record the line pressure and rate of flow.
4. Calculate the resistance in each case and determine the resistance per foot of hydraulic hose.
5. With the 25-ft line in place, insert a quick connection between the pressure gauge and the flow meter and determine its resistance.
6. By the same method as step five, determine the resistance of a relief valve, check valve, pressure gauge, and flow meter.
7. Record all values in the data table, figure 1-5, for future use.

ANALYSIS GUIDE. In analyzing this experiment, you should discuss possible errors in determining the components' values. Explain why you feel this experiment has or has not reached its objective. Can you think of other methods of determining resistance in fluid systems?

COMPONENT	PRESSURE	FLOW RATE	RESISTANCE
25 ft Hose (¼")			
1 ft Hose (¼")			
Quick connection			
Relief Valve			
Check Valve			
Pressure Gauge			
Flow meter			
RESISTANCE VALUES			
¼" Hydraulic Hose per foot			
Quick connection			
Relief valve			
Check valve			
Pressure gauge			
Flow meter			
CALCULATIONS			
Resistance = $\frac{\text{Pressure Diff.}}{\text{Flow rate}}$ in units of $\frac{\text{psi}}{\text{gal/min}}$			

Fig. 1-5 Data Table

PROBLEMS

1. What is the pressure drop across a series system containing six quick disconnect couplers, 78 ft of $\frac{1}{4}$ " hydraulic hose, and two flow meters if the rate of flow is five gal/min?
2. What is the rate of flow of a series system containing 38 ft of $\frac{1}{4}$ " hydraulic hose, six pressure gauges and 15 connectors if a pressure drop of 330 psi is maintained in the system?
3. Find the resistance of a system having a flow rate of 38.5 gal/min under a pressure of 466 psi.

experiment 2 PARALLEL FLUID FLOW

INTRODUCTION. The purpose of this experiment is to examine fluid resistance as it occurs in a parallel fluid circuit.

DISCUSSION. In order to understand fluid systems, it is necessary to become acquainted with some of the elementary characteristics of fluid motion. Fluids, substances which flow easily, include both liquids and gases. The only difference between the two, for our purposes, is that gases may be easily compressed while liquids allow only very slight compression.

All fluids have some degree of *viscosity*. Viscosity is the internal friction drag of one part of the fluid on a neighboring part of the same fluid. Some fluids are much more viscous than others a fact we can see by comparing the flow of water to that of honey. Hydraulic fluid, which we will be using, has relatively little viscosity and can be dis-

regarded in many flow situations. We shall assume that hydraulic fluid is not compressible.

Another characteristic of fluid flow that we must consider is the type of motion that the fluid exhibits. We will assume that our fluids move with a type of motion known as *laminar flow*. With steady laminar flow, as shown in figure 2-1, the particles of fluid travel in fixed paths side by side. At the other extreme is *turbulent flow*, which is characterized by whirls and eddies much like a cloud of smoke or a stream of water going over rocks. Turbulence usually occurs at high speeds. If the velocity of flow in a pipe is very high, the flow will be classified as turbulent. Turbulent flow is illustrated in figure 2-2.

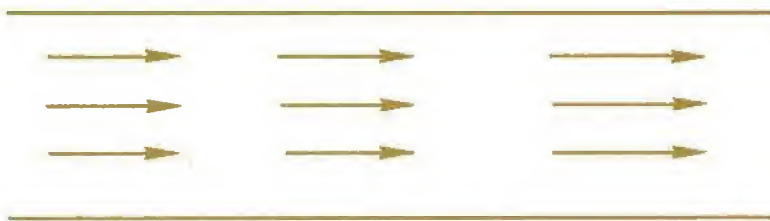


Fig. 2-1 Laminar Fluid Flow

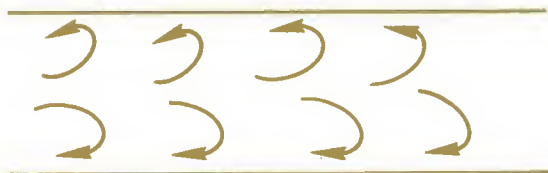


Fig. 2-2 Turbulent Flow

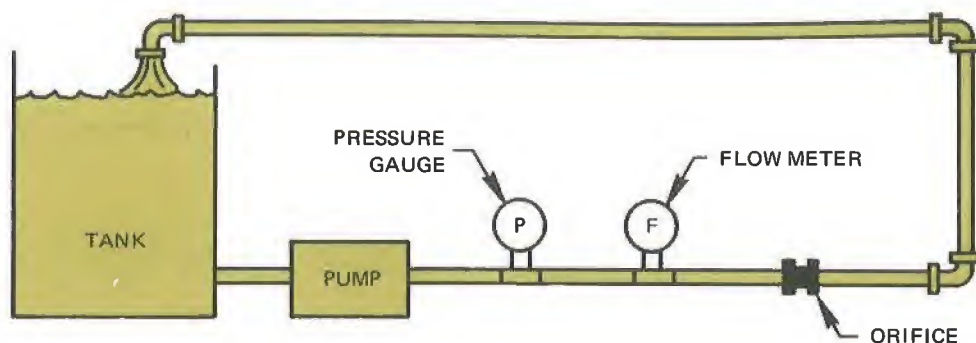


Fig. 2-3 Series Hydraulic Circuit

To maintain real fluids in motion, energy must be expended just as it is in the case of electrical currents or the mechanical motion of solid bodies. The concepts are similar for all these cases, but the units differ. Just as the unit of electrical resistance is measured by the electric potential difference required to maintain a flow of one coulomb per second, so is fluid resistance measured by the pressure drop or difference required to maintain a flow of one gallon per minute or one cubic foot per minute.

In a series circuit such as the one in figure 2-3 we can observe the relation of pressure to quantity of fluid flowing in the system. As the pressure is increased, the fluid flow rate is increased. If a small orifice is placed in the circuit, the flow rate (the quantity of fluid per unit time passing through it) is decreased for the same pressure. If we consider the flow resistance in the orifice, then we can state symbolically that

$$R = \frac{\Delta P}{Q} \quad (2.1)$$

where ΔP is the pressure difference across the system, R is the resistance, and Q is the quantity of fluid transported per unit time in the system.

If we increase the length of pipe or insert another orifice, the resistance is increased, thus giving us a reduced flow rate and a new total resistance. This new total resistance can be found by adding the initial resistance and the resistance of our second orifice or extra pipe length.

$$R_T = R_1 + R_2 \quad (2.2)$$

If we again consider a pipe system, but this time a parallel system as in figure 2-4, we can again see our basic relationships. When the resistance in branch A of the system is equal to the resistance in branch B, we can compute the total resistance by the equation

$$R_T = \frac{R}{N} \quad (2.3)$$

where N is the number of branches. If, however, the resistance of the two branches is not equal, we must use the equation

$$R_T = \frac{R_1 R_2}{R_1 + R_2} \quad (2.4)$$

Should there be more than two resistances in parallel we need to use yet another equation.

This equation for more than two resistances in a parallel configuration is

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}} \quad (2.5)$$

The individual resistance in each branch line is treated as an individual series circuit.

Many pipe and electrical systems are parallel types; therefore, in this experiment we will examine parallel pipe flow systems.

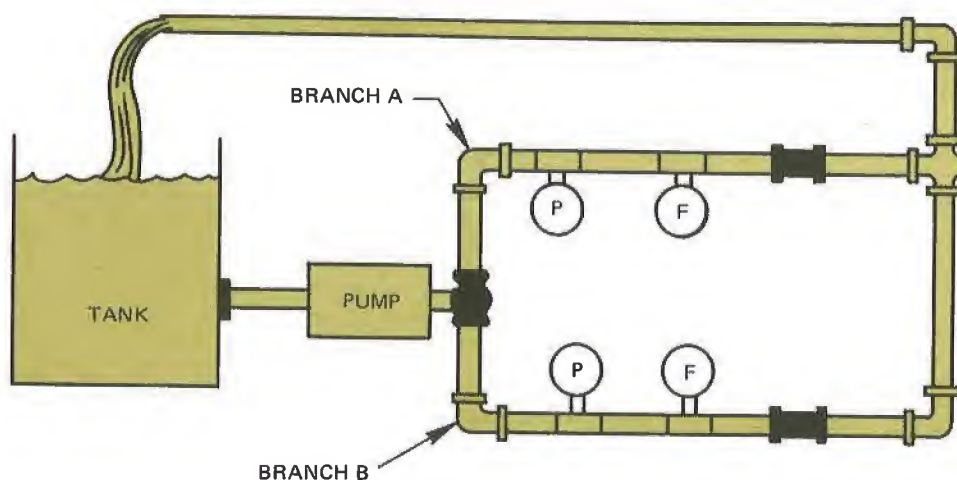


Fig. 2-4 Parallel Hydraulic Circuit

MATERIALS

- | | |
|--------------------------------------|---|
| 1 Hydraulic pump | 1 Adjustable flow control valve |
| 1 25-ft length of hydraulic hose | 1 10-qt graduated container |
| 2 5-ft lengths of hydraulic hose | 1 Stop watch |
| 1 Pressure gauge | 1 2-ft length of plastic hydraulic hose |
| 1 Pressure relief valve (adjustable) | 10 Quick disconnect couplers |
| 2 Flow meters | Assorted hydraulic fittings as needed |

PROCEDURE

1. Set up the experimental system shown in figure 2-5.

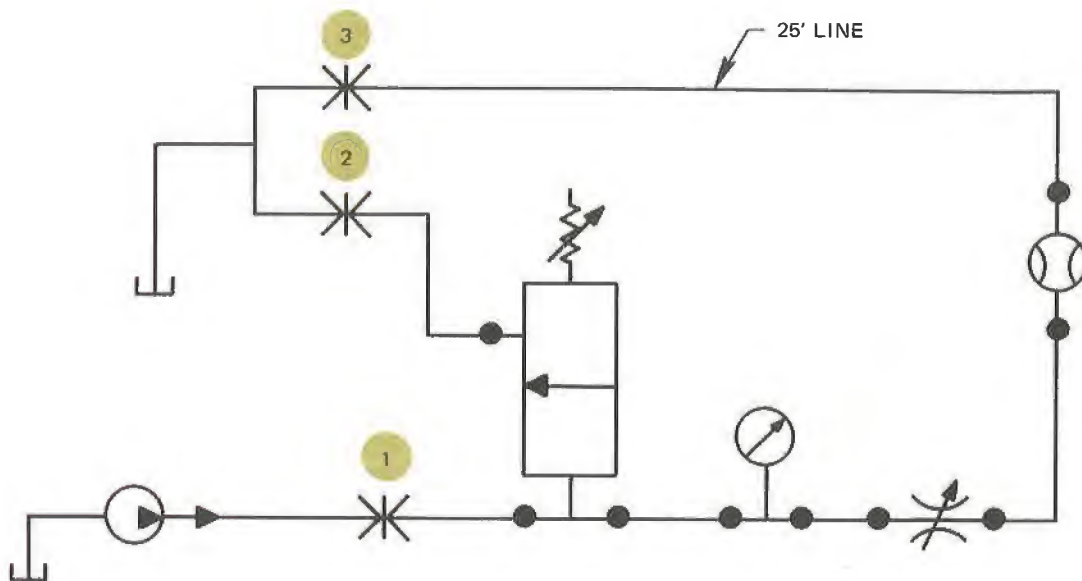


Fig. 2-5 Flow Mechanism

2. Turn on the pump, and with the PRV and the flow control valve, adjust the flow to 1 GPM.
3. Record the pressure and calculate and record the resistance of the system. Resistance should be shown in units of $\frac{\text{psi-min}}{\text{gal}}$.
4. Disconnect the line at connection three and with a graduated 10-quart container and a stopwatch, measure and record the fluid expelled by the system in one minute. *CAUTION: Be sure that the reservoir is full and return the fluid after measuring.* If a graduated container is not available a glass jar may be calibrated with a measuring cup, indicating levels on a piece of masking tape.
5. Modify the system to that shown in figure 2-6.
6. Adjust the PRV and the flow control valve until the total flow rate is 1 GPM.
7. Measure and record the flow and pressure of each branch of the system and calculate and record the resistance of each branch and the total resistance.
8. Add a second 5-foot length of hose in series with the present one and repeat step 7.

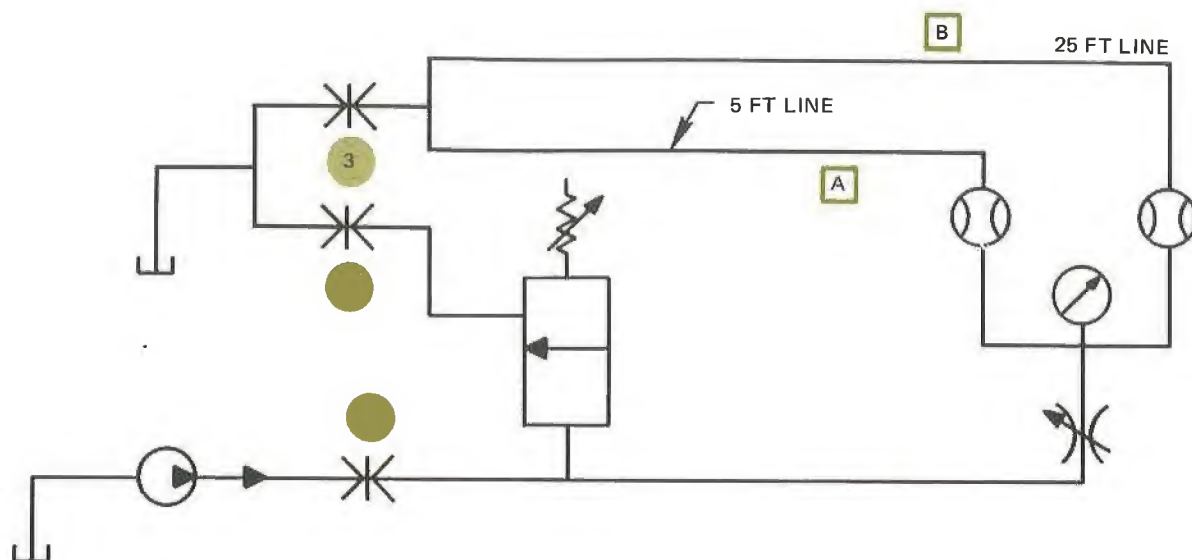


Fig. 2-6 Parallel Fluid System

		PRESSURE	FLOW RATE	RESISTANCE	CALCULATIONS
Circuit One (flow meter)					
Circuit One (measured)					
Circuit Two Part One	A				
	B				
	Total				
Circuit Two Part Two	A				
	B				
	Total				
Circuit Two - measured					

Fig. 2-7 The Data Table

9. Disconnect the line at connection three. Using the graduated container and stop watch, catch and record the fluid flow for one minute.
10. Compare the results with those calculated.

ANALYSIS GUIDE. In the analysis of this experiment you should determine the flow rate and resistance of the flow mechanism. Explain the concept of flow rate through different lengths of pipe and draw an analogy with electrical flow. Determine the percentage of error of the flow meter. Make a statement of the relationship between series and parallel pipe systems.

PROBLEMS

1. A fluid system is running at 10 GPM under a pressure of 100 psi. If the pressure is changed to 250 psi, what is the new flow rate?
2. A parallel system is made up of three branches. Branch A has a resistance of 18 (psi-min)/gal; Branch B, 30 (psi-min)/gal, and Branch C, 38 (psi-min)/gal. What is the total resistance of the system?
3. A series system has a pressure of 436 psi and a flow rate of 7.6 GPM. What would be the new pressure required if the system is split into two equal branches and kept at the same flow rate? Assume no added connection resistance and that each new branch has half the resistance of the original system.

experiment 3 SERIES-PARALLEL FLUID FLOW

INTRODUCTION. Series-parallel flow systems are more complex than either series or parallel and are often used in distribution. The purpose of this experiment is to examine the flow pattern of this type of system.

DISCUSSION. An understanding of the basic principles associated with series and parallel circuits is a sufficient background to approach more complicated *series-parallel networks* (any network which is a combination of any number of series and parallel elements). In a series-parallel network either series or parallel circuits may exist within the same system.

Figure 3-1 illustrates pipes 2 and 3 in parallel (points a and b are common) while the fluid source is in series with pipes 1 and 4. The parallel combination of pipes 2 and 3 is also in series with 1, 4, and the fluid source. The flow rate, Q , of a series-parallel network is much like the action of a similar electrical circuit.

To maintain fluids in steady motion requires differences in pressure. In series circuits the resistance, R , is directly proportional to the difference in pressure, P , and inversely proportional to the flow rate, Q . In a parallel circuit the individual paths act as series paths. The total resistance, R_T , in all the parallel branch circuits is less than the least resistance in any branch circuit:

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n}} \quad (3.1)$$

The pressure drop across a parallel circuit is the same for all available paths and Q_p , the total parallel flow rate, is the sum of the rates

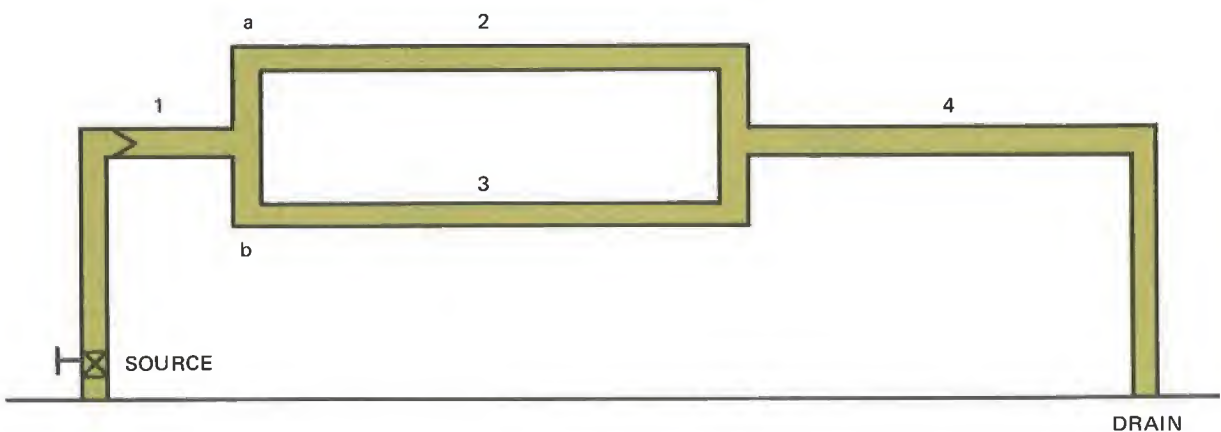


Fig. 3-1 Series-Parallel Piping Network

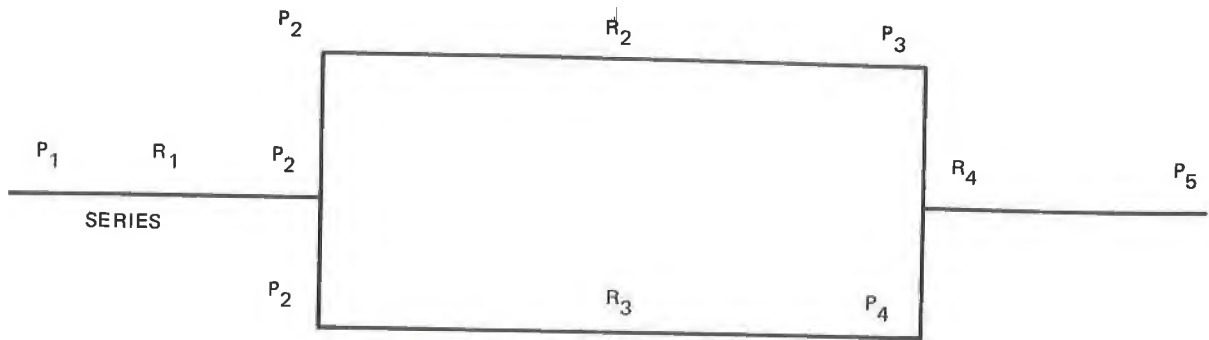


Fig. 3-2 Resistance and Pressure Drop in a Series-Parallel Network

of the individual paths. In the series-parallel circuit shown in figure 3-2, the total resistance, R_T , is equal to the series and parallel resistance, $R_S + R_P$. The total resistance is directly proportional to the sum of the pressure drops across both the series and parallel circuits and the resistance, R_T , is inversely proportional to the total flow rate, Q_T .

As seen in the preceding case, a series-parallel system is one in which some portions

of the system have the characteristics of simple series circuits and other portions have the characteristics of simple parallel circuits. Systems of this type present special problems when calculating resistance of branch components and total resistance.

The method of solution can best be seen by considering an example such as the one shown in figure 3-3.

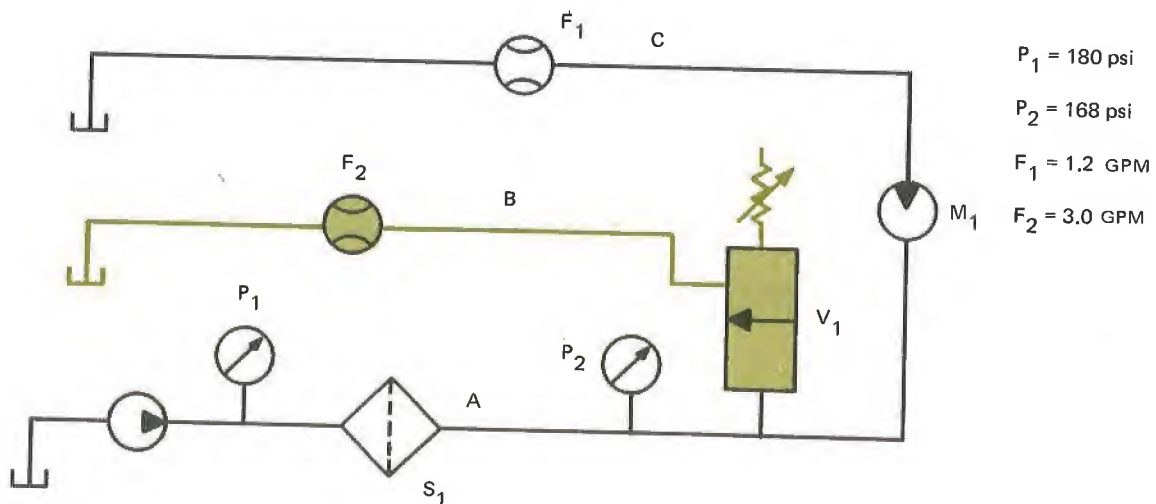


Fig. 3-3 Series-Parallel Fluid System

This system contains three main branches: Branch A contains a filter and S_1 ; Branch B has a flow meter, F_2 , and the bleed-off return of the relief valve, V_1 ; Branch C contains a hydraulic motor, M_1 , and flow meter, F_1 .

A simple method of solving for the resistance of this system is to reduce the system to a simple series circuit. By visual inspection we can see that the bleedoff line is in parallel with the motor branch. We must first compute the resistance of each separate branch.

$$\begin{aligned}\text{Branch C: } R_B &= \frac{P_2}{F_1} \\ &= \frac{168}{1.2} \\ &= 140 \text{ psi-min/gal}\end{aligned}$$

$$\begin{aligned}\text{Branch B: } R_C &= \frac{P_2}{F_2} \\ &= \frac{168}{3.0} \\ &= 56 \text{ psi-min/gal}\end{aligned}$$

Since these two branches are in parallel, they may be combined as follows:

$$R_T = \frac{R_1 R_2}{R_1 + R_2} \quad (3.2)$$

$$\begin{aligned}R_{eq} &= \frac{R_B R_C}{R_B + R_C} = \frac{56 (140)}{196} \\ &= 40 \text{ psi-min/gal}\end{aligned}$$

This result is consistent with the principle that for parallel connection the combined total must be less than either of the two branches separately. We have now reduced the system to a simple series circuit. Our next step is to compute the resistance value for branch A. The flow rate through the filter in branch A is the sum of the flow rates through branches A and B or 4.2 GPM. The resistance of branch A is

$$\begin{aligned}R_A &= \frac{\Delta P}{Q} = \frac{180 - 168}{4.2} \\ &= 2.85 \text{ psi-min/gal}\end{aligned}$$

The total resistance of the system is the sum of the equivalent series component parts; therefore, the total resistance of this system is 42.85 psi-min/gal.

Most practical fluid flow systems are parallel or series-parallel in nature; therefore, the purpose of this experiment is to examine a series-parallel fluid system.

MATERIALS

- | | |
|---------------------------|------------------------|
| 1 Hydraulic pump unit | 1 Hydraulic motor |
| 2 Flow meters | 1 Flow control valve |
| 2 Pressure gauges | 1 25-ft hydraulic hose |
| 1 Adjustable relief valve | 1 Stroboscope |

PROCEDURE

1. Set up the fluid system shown in figure 3-4.

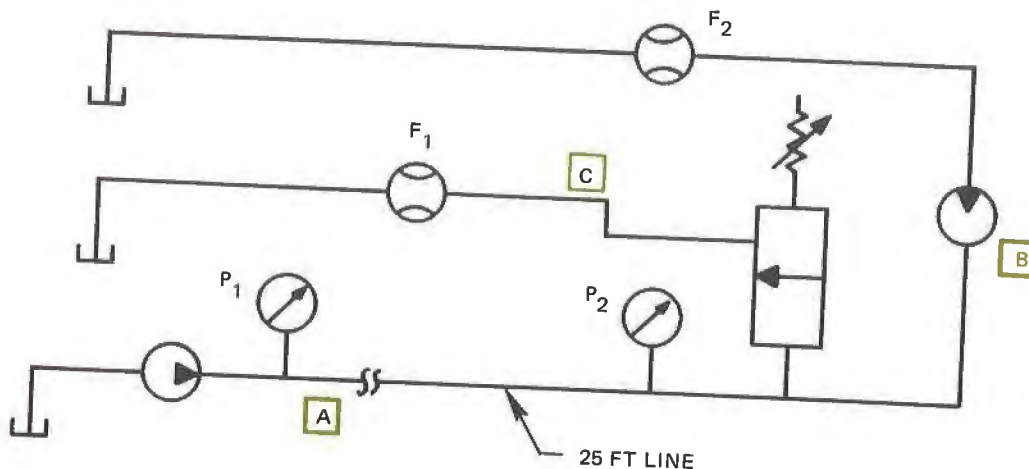


Fig. 3-4 The Experimental System

2. Start the pump and set the relief valve to cause all of the fluid to flow through the motor.
3. Adjust the pump until the flow is 3.0 GPM.
4. Record the pressures (P_1 and P_2) and calculate the resistance of branches A and B.
5. Adjust the relief and flow control valves to allow all fluid to pass through branch C and adjust the pump to a flow of 3.0 GPM. Record the pressure and calculate the resistance of branch C and of the total system.
6. Increase the flow rate in branch B from zero to 3.0 GPM in 0.25 GPM steps. With the stroboscope measure the RPM of the motor at each step.
7. Make a plot of RPM versus flow rate.

ANALYSIS GUIDE. In the analysis of this report you should determine the flow rate and resistance of the series-parallel network. Explain the concept of flow rate in a series-parallel system and make an analogy with mechanical flow. Plot a diagram showing the relationship of motor RPM versus flow rate and comment on the shape of the plot. Explain how a motor may be used as a flow meter.

BRANCH	PRESSURE	FLOW RATE	RESISTANCE	FLOW RATE VERSUS RPM					
				GPM	RPM	GPM	RPM	GPM	RPM
A				0.25		1.25		2.25	
B				0.50		1.50		2.50	
C				0.75		1.75		2.75	
Total				1.0		2.0		3.0	

Fig. 3-5 The Data Table

experiment 4 NONLINEAR OPPOSITION

INTRODUCTION. Resistance is frequently encountered in fluid systems. However, there is a characteristic of resistance which is seen quite often and which is equally often ignored. That characteristic is *nonlinearity*. A nonlinear resistance has a resistance value which changes depending on the operating conditions. In this experiment, we shall examine nonlinear resistance in pneumatic and hydraulic systems.

DISCUSSION. Linear resistance has a constant value of resistance under normal circumstances. If the resistance of a device is constant, then the flow rate through it will double if the pressure difference is doubled. The effect may be noted by the equation

$$Q = \frac{P_1 - P_2}{R} \quad (4.1)$$

In the case of *nonlinear opposition*, however, the resistance value changes as the operating conditions change. That is, the resistance varies as the pressure difference and flow rate change.

One good way to determine experimentally if a system is linear or nonlinear is to double the value of an input and find if the corresponding output value is doubled. For example, when a pipe expands, the flow rate, pressure, and resistance will all change. Equation 4.2 will show this variable relationship.

$$R = \frac{P_1 - P_2}{Q_1 - Q_2} = \frac{\Delta P}{\Delta Q} \quad (4.2)$$

It may be shown experimentally that as a fluid is flowing through an expandable tubing

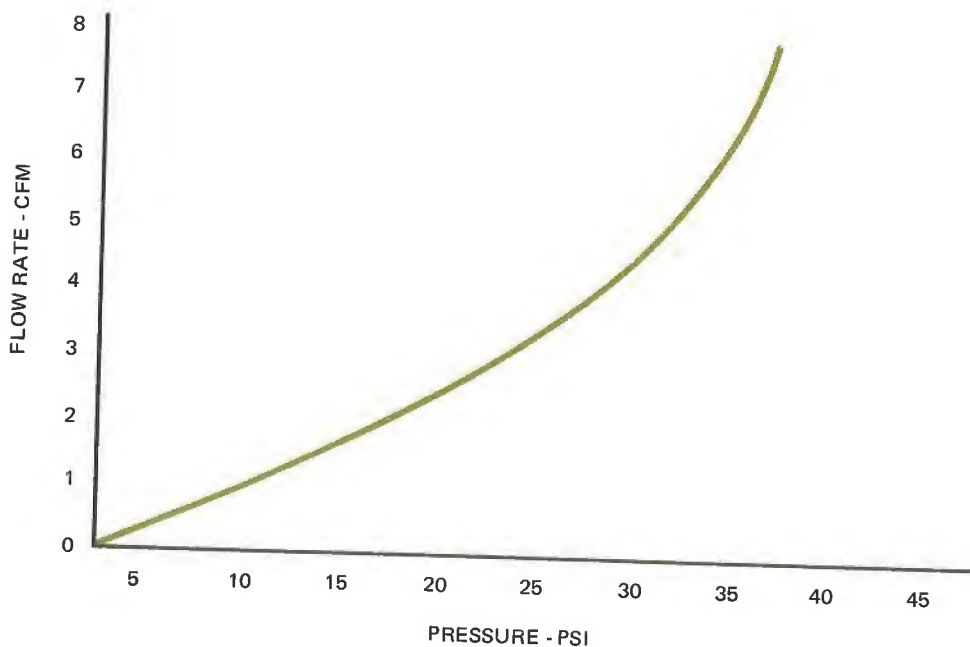


Fig. 4-1 Q-P Plot of Nonlinear Opposition

the pressure will increase to the stretch point of the pipe. When this point is reached and the pipe begins to stretch, the pressure will tend to stabilize. At this point the pressure will remain approximately constant and the pipe will do two things: get longer and increase in cross-sectional area. Using this information we may conclude that the flow rate, Q , will vary but will not vary linearly. If the flow rate varies and the pressure remains constant, then the opposition must vary as shown in equation 4.2. In the case of nonlinear opposition, the resistance value changes as operating conditions change. In other words, the resistance varies as the flow rate varies. The Q - P plot of a device will not be a straight line. Figure 4-1 shows a nonlinear Q - P plot.

If we compute the opposition value at several points along the curve, the resistance will be different at each point. Let us consider, for example, flow rates of 1, 3, and 6 CFM.

(for $Q = 1$ CFM)

$$R_1 = \frac{10}{1} = 10 \text{ psi/CFM}$$

(for $Q = 3$ CFM)

$$R_2 = \frac{25}{3} = 8.33 \text{ psi/CFM}$$

(for $Q = 6$ CFM)

$$R_3 = \frac{35}{6} = 5.83 \text{ psi/CFM}$$

Let's look beyond fluid flow in pipes for a moment and consider a parachute falling. At an altitude of 30,000 feet the pressure is about 4 psi and may not offer enough resistance to open the parachute. As the chute gets closer to the ground, the pressure increases and so does the resistance. Eventually the resistance gets large enough to open the chute. Let us consider a mechanical spring next: when a force is slowly applied and released, the force-displacement can be shown graphically by the plot in figure 4-2. This type of behavior is often called *hysteresis*. The hysteresis effect involves energy loss which is represented by the shaded portion of the graph.

There are many other examples of non-linearity but the foregoing examples are sufficient to illustrate the basic idea.

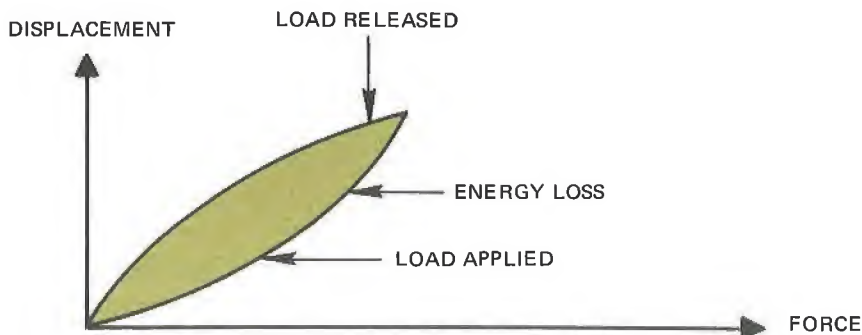


Fig. 4-2 Nonlinearity of a Spring

MATERIALS

- | | | | |
|---|--|---|---|
| 1 | 0-50 psi Air supply | 1 | 1 ft Surgical hose $\frac{1}{4}$ in. ID |
| 1 | 1 ft Pneumatic hose $\frac{1}{4}$ in. ID | 2 | Hose clamps $\frac{1}{4}$ in. |
| 1 | 3 ft Pneumatic hose $\frac{1}{4}$ in. ID | 1 | 0-30 psi Pressure gauge |
| 1 | Flowmeter (pneumatic) | 1 | 36 in. Ruler |
| 1 | Flow control valve | 1 | Vernier caliper |

PROCEDURE

1. Set up the experimental pneumatic system shown in figure 4-3.

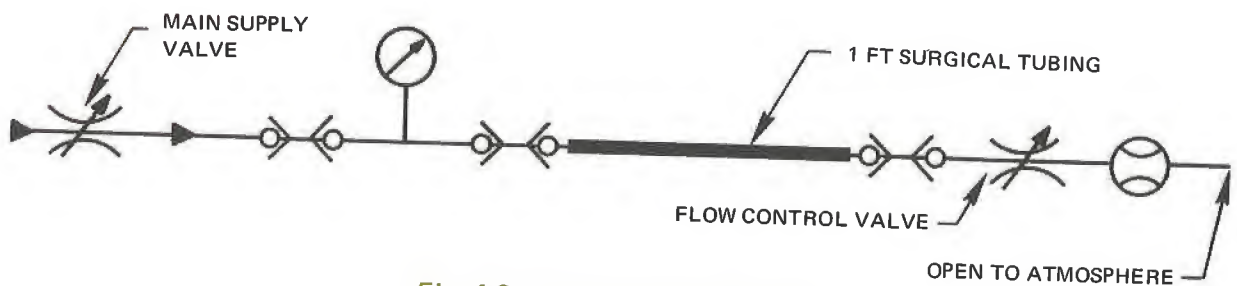


Fig. 4-3 Experimental System

2. With the flow control valve all the way open, open the main supply valve until the flowmeter reads 0.5 CFM.
3. Begin closing the flow control valve until the pressure gauge registers 0.5 psi. This is the only adjustment needed with the flow control valve as its purpose is to act as an orifice.
4. Measure and record the surgical tube diameter and length and the gauge pressure in the data table, figure 4-4.
5. Increase the flow rate using the main supply valve in steps of 0.1 CFM, being sure to record all required data for each step in the data table. Calculate the resistances in psi-min/cubic ft. *CAUTION: Do not touch the tubing with sharp instruments. Do not apply pressures above 5 psi more than the value required to balloon the tubing.*
6. Continue to increase the flow until the tube balloons and then go one more 0.1 CFM step.
7. Decrease the flow in 0.1 CFM steps and record the pressure at each step.
8. Plot graphs of the flow rate versus the tube diameter, flow rate versus tube length, and flow rate versus pressure.

FLOW RATE	DIAMETER	LENGTH	PRESSURE	RESISTANCE
0.5				
0.6				
0.7				
0.8				
0.9				
1.0				
1.1				
1.2				
1.3				
1.4				
1.5				
1.6				
1.7				
1.8				
1.9				
2.0				

Fig. 4-4 The Data Table

ANALYSIS GUIDE. In analysing the results of this experiment you should discuss the graphs which you have drawn. Does the data tend to support the material presented in the discussion? How well has this experiment achieved its objective?

experiment 5 STATIC STORAGE

INTRODUCTION. The objective of this experiment is to gain an understanding of static energy storage.

DISCUSSION. The reservoir in the fluid system is a storage tank. There are many types of static storage apparatus: the water reservoir or dam, the city water tower, the gas tank in the automobile.

The static storage tank serves many purposes but there are three prominent reasons for its use. They are to maintain a constant pressure head, to allow heat to be removed, and to store energy. The first is perhaps best illustrated by the city water tower. The water is raised to a height which causes a pressure great enough to supply adequate faucet pressure at homes in the city.

The removal of heat by a reservoir is necessary because of the high pressures found in many hydraulic systems. An example of this heat removal is seen in the automobile radiator.

The third purpose of reservoirs, energy storage, is shown by water stored behind a dam. The water possesses energy because of its higher position than the place into which it empties. Of course, energy is also stored in a city water tower. This type of energy is known as *potential energy*. Potential energy may be defined as the ability of a body to do work because of its relative position with respect to other bodies.

An object that has been raised some distance above a floor has potential energy because of its relative position with respect to the floor. When it is allowed to fall, the earth pulls it downward and thus enables it to move

other objects or do work. The potential energy of a body is measured by the maximum amount of work it is able to do. In the case of a raised weight, its potential energy is the difference between its energy at its highest position and its energy when it reaches the floor.

To compute the potential energy of a body we simply compute the work needed to raise it from the lowest position to its highest position. Work is equal to the weight of the body, w , times the height, h , it was lifted.

$$\text{Potential Energy} = h \times w$$

and since weight = mass $\times$ acceleration due to gravity

$$\text{PE} = mgh \quad (5.1)$$

After the mass is released, the potential energy becomes *kinetic energy* (energy of motion), therefore:

$$\text{PE} = \text{KE} = mgh = \frac{1}{2} mV^2 \quad (5.2)$$

where V is the velocity of the mass when the body reaches its lowest position.

Consider liquid flowing from a static storage water tank: the liquid pressure equals the atmospheric pressure at the top of the tank and at the orifice. See figure 5-1.

If the orifice is small compared with the cross section of the tank, the liquid in the tank will fall slowly enough for the change in level of the liquid at the top of the tank to be

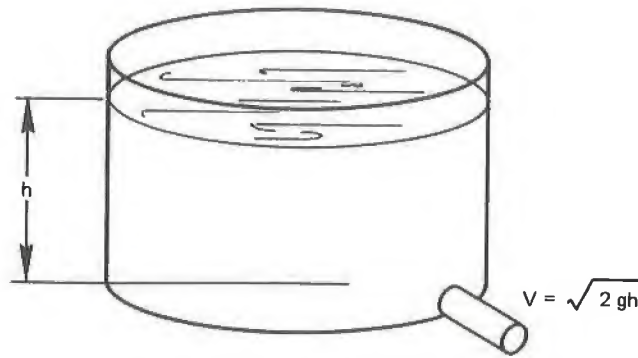


Fig. 5-1 A Tank Representing Torricelli's Theorem

neglected. If the speed of the liquid as it leaves the orifice is V and the difference in height between the top of the liquid and the orifice is h , then the velocity, $V = \sqrt{2gh}$. This is Torricelli's theorem. The speed with which the liquid is discharged is the same as the speed of a body falling from rest from the height, h .

For this experiment we will use a tank elevated in the air as shown in figure 5-2 with an

outlet at the bottom. The flow rate at which the liquid leaves the orifice is determined by

$$Q = VA = A \sqrt{2gh} \quad (5.3)$$

where

Q = flow rate in cu ft/sec

V = velocity in ft/sec

A = effective area of the opening in ft^2

$g = 32 \text{ ft/sec}^2$

h = height from top of the liquid to the orifice in ft

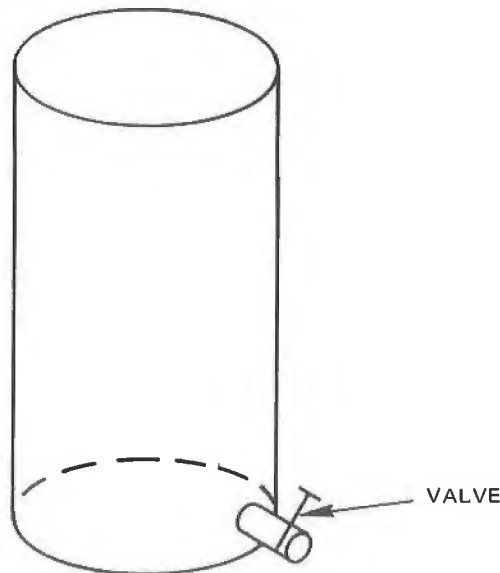


Fig. 5-2 Static Storage Tank

MATERIALS

- 1 16 Gal. tank (storage) with outlet and valve at the bottom.
- 1 Stop watch
- 1 Gallon container
- 1 Meter stick

PROCEDURE

1. Measure the tank dimensions.
2. Determine the volume.
3. Determine the mass of the water.
4. Fill the tank.
5. Collect ten one-gallon samples of water and record the level of the water and time in the data table in figure 5-3.

	READING									
SAMPLE NO.	1	2	3	4	5	6	7	8	9	10
TIME IN SECONDS										
WATER LEVEL IN FEET										
FLOW RATE										

Fig. 5-3 Data Table

6. Calculate and record the flow rates.
7. Plot a graph of water height vs flow rate.
8. Determine the potential energy of the portion of the water drained from the tank.
9. Determine the kinetic energy of the water leaving the tank.

ANALYSIS GUIDE. In analyzing your experimental data you should explain the concept of static (potential) energy storage. How is the flow rate affected by the liquid height? As a check of your data, use equation 5.3 to find the area opening, being careful of units.

PROBLEMS

1. What is the potential energy of a block of concrete weighing 210 lbs at a height of 236 inches?
2. A fluid leaves a storage tank at a speed of 15 ft/sec. What is the flow rate if the outlet has a diameter of 3.0 inches?
3. What is the diameter of the opening of a circular orifice passing fluid at 9.6 ft/sec? The fluid flow rate is 300 gallons per minute.

$$1 \text{ gal/min} = 2.228 \times 10^{-3} \text{ ft}^3/\text{sec}$$

4. What is the kinetic energy of 360 ft^3 of water in a tank behind the orifice of problem three?

experiment 6 THERMAL TIME CONSTANTS

INTRODUCTION. Thermal time constants are similar to those encountered in fluid or electrical systems. Time constants determine how long it takes for a system to change from one flow rate to another. The purpose of this experiment is to examine thermal resistance and determine the thermal time constant of a thermal system.

DISCUSSION. We know that it takes time for the flow of a quantity of energy, charge or mass through a system. Likewise, we know that a difference in temperature causes heat flow from one body or place to another. In general terms, the resistance to flow of a material or system can be expressed as follows:

$$R = \frac{P_1 - P_2}{Q} \quad (6.1)$$

where Q is the flow rate and $P_1 - P_2$ is pressure difference for fluid flow, voltage drop for electric charge flow and temperature difference for heat flow in a material.

The time may be expressed in any desired units consistent with other conditions. So, if we deal with charge flow, the normal units of time would be seconds. If we deal with thermal flow, the units may be British Thermal Units (BTU) per second or BTU s per minute.

The thermal resistance of a material tends to remain more or less constant in most cases provided that the temperature difference is small compared to the temperature at which the heat transfer takes place. If a film of still water surrounds a piece of material which is being heated, it will take a greater temperature difference or a longer period of time to transfer the same amount of heat than if the water were being agitated. If a pipe is corroded, the pressure difference must be increased to maintain a given flow. From this it can be seen that the resistance of a com-

ponent, regardless of the type of flow involved, may depend on a variety of conditions.

If a glass thermometer is moved from ice water to water at some higher temperature, the indicated temperature of the new conditions will be reached only after some period of time. If the difference in water temperature were not so great and the water is not agitated, it will take a longer period of time for the temperature to be reached. Because the rate at which thermal energy will be transferred varies with the temperature difference and because it is difficult to maintain a constant difference, the rate of transfer should be computed at each instant. The initial transfer rate is determined from initial conditions.

EXAMPLE.

Given: 5 pounds of water
 Water temperature $T^\circ = 32^\circ\text{F}$
 Water temperature $T_2 = 212^\circ\text{F}$
 Time 6 minutes

Find: Thermal resistance R

Solution: The amount of heat transferred to the water is: (wt. of water) $\times$ (specific heat capacity) $\times$ (change in temp. $^\circ\text{F}$) = (heat transferred BTU)
 $(5 \text{ lb}) (\text{BTU/lb/}^\circ\text{F}) (212 - 32^\circ) = 900 \text{ BTU}$

$$R = \frac{(\Delta t) (\text{time})}{\text{Heat transferred}} = \frac{180 \times 6}{900} = \frac{1.2^\circ \text{ minutes}}{\text{BTU}} \quad (6.2)$$

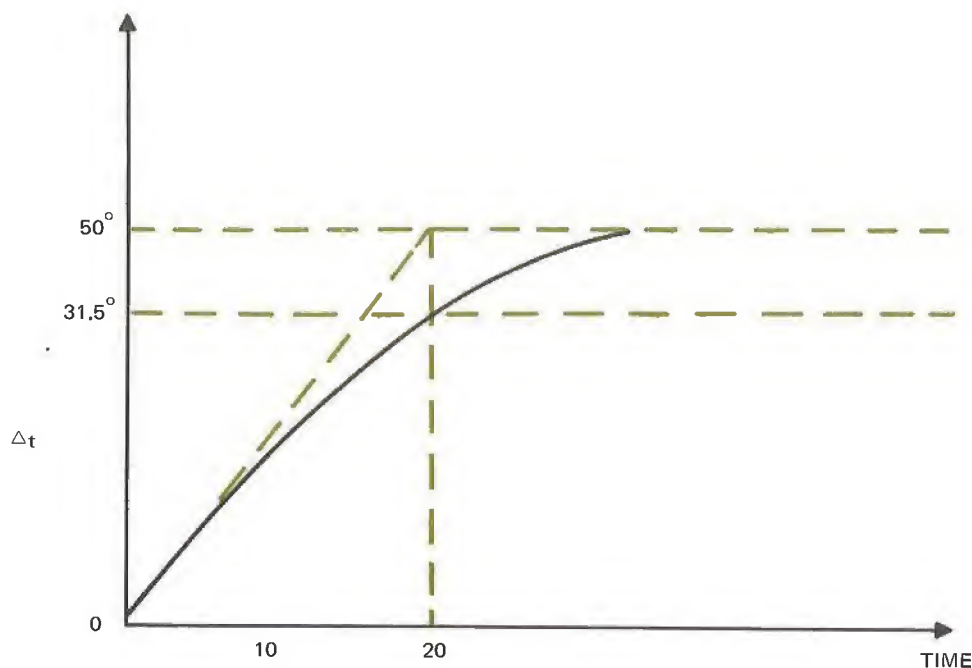


Fig. 6-1 Relative Time Constant per Degree Change

Because energy cannot be transferred instantaneously but requires some period of time, it is useful to be able to predict the time required for a certain amount of transfer to take place. The time interval known as the *time constant* indicates the period required to complete the process when the transfer continues at its initial rate. If we were to plot the temperature versus time, it would have a shape somewhat as shown in figure 6-1.

If we plot the actual temperature change versus time for such a process we will find that at the end of the predicted 20 seconds, the change in temperature is only 63% of what was expected based on original rate of heat transfer. This same percentage will be found with all types of step changes in input where there is but a single resistive unit and a

single storage element. The same relationship holds whether we are dealing with thermal, mechanical, or fluid systems. *We must re-emphasize that the system always undergoes 63% of the total change during the first time constant and completes 63% of the remaining change during each succeeding time constant.*

In this experiment we will treat thermal time constants from two standpoints. First, we will use a container of water and bubble steam into it and measure time and the temperature change as the water heats. In the second part of the experiment we will put a beaker of water in an ice bath and let the water cool until the water nears the temperature of the ice. We will plot the time versus the temperature and compare the plotted information with the theoretical 63% value given in the discussion.

STEAM NO. 1

TIME-SEC	0	15	30	45	60	75	90	105	120	135	150	165	180
TEMP.° F													

ICE NO. 1

TIME-MIN	0	3	6	9	12	15	18	21	24	27	30	36	39	42	45
TEMP															

STEAM NO. 2

TIME-SEC	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	240	255	270
TEMP																		

ICE NO. 2

TIME-MIN	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
TEMP																					

Fig. 6-2 The Data Table

MATERIALS

- 2 32 - 212°F thermometers
- 1 Steam supply (or other heat source)
- 1 1000 ml beaker
- 2 225 ml flasks
- 5 lb ice (crushed)

PROCEDURE

1. Fill the two flasks and let them stand until the water is near room temperature.
2. Insert the steam line into one of the flasks and let steam bubble slowly through the water. Read and record in the data table, figure 6-2, the temperature at 15-second intervals until the water reaches a constant temperature.
3. Place the second flask in the beaker and pack ice around it.
4. Read and record in the data table the temperature at 3-minute intervals until the water temperature reaches a constant temperature.
5. Switch the flasks and repeat steps 2 through 4. Add ice when needed.
6. Plot graphs of the temperature versus time in all four cases. Place the two increasing functions on one set of coordinates and the two decreasing functions on another.

ANALYSIS GUIDE. In the analysis of this experiment you should calculate the time constants of each curve and compare them to each other. Do the curves tend to support the information given in the discussion? What might cause variations in thermal systems which could affect the validity of the experimental data?

PROBLEMS

1. What temperature will a system reach after one time constant if the total temperature is 75°F?
2. If 36 cubic feet of water is heated in a water heater, what will be the temperature reached if the amount of heat transferred is 11,300 BTU? The initial temperature is 36°F.
3. In the first case of this experiment, calculate the heat transferred and thermal resistance. 1 ml. of water = 0.0021 lbs.

experiment 7 HYDRAULIC TIME CONSTANTS

INTRODUCTION. Hydraulic time constants are similar to those in pneumatic or electrical processes. The purpose of this experiment is to determine the time constants for various simple conditions, and the relationship between theoretical and experimental concepts when step changes are involved.

DISCUSSION. We know that it takes time for the fluid of a quantity of energy, mass, or charge through a system. In general terms, the resistance to flow of a material or system can be expressed as follows:

$$R = \frac{P_1 - P_2}{Q} \text{ or } \frac{(P_1 - P_2)}{\text{flow rate}} \quad (7.1)$$

$P_1 - P_2$ is pressure difference for fluid flow, voltage drop for charge flow and temperature difference for heat flow in a material. When dealing with any such situations, the time may be expressed in any desired units consistent with other conditions, i.e., if we deal with coulombs the normal units of flow rate would be coulombs per second. In dealing with other types of flow the units may be transferred to any appropriate units.

Resistance tends to remain more or less constant with certain types of materials provided that temperature and the physical size of the conductor remains constant. If the resistance changes, the potential energy difference must be changed in order to keep the flow at its original level. If a pipe corrodes, the pressure difference likewise has to be increased to maintain a given flow.

From this it can be seen that the resistance of a given component, regardless of the type of process involved, may vary with a variety of conditions. It must be re-emphasized that the resistance can be computed with the use of equation 7-1, i.e.,

$$R_{\text{Hydraulic}} = \frac{(P_1 - P_2) (\text{time})}{\text{amount of liquid through the pipe}}$$

This resistance, the properties of the liquid and the pipe cross-section, determines the time constant.

Because energy, mass or charge cannot be transferred instantaneously but requires some period of time, it is useful to figure the time required for such transfers to take place. This is simple for the case that the initial conditions continue to exist. For abrupt and step changes in conditions, this time is known as the *time constant* and indicates the period required to complete the process when the transfer continues at its initial rate. If we plot the pressure of a hydraulic fluid with respect to time, it would have a nonlinear shape as shown in figure 7-1.

If we carefully plot P vs time, for a step change, we will find that at the end of the predicted 20 seconds the change in pressure is only 63% of what was expected based on original rates of transfer, which is indicated by the dashed line of figure 7-1. This same percentage of predicted value to actual value will be found with all types of step change in input where there is but a single resistive unit and capacitance in series. The same relationship holds whether we are dealing with fluid flow or thermal systems. We must re-emphasize the system always undergoes 63% of the total change during the first time con-

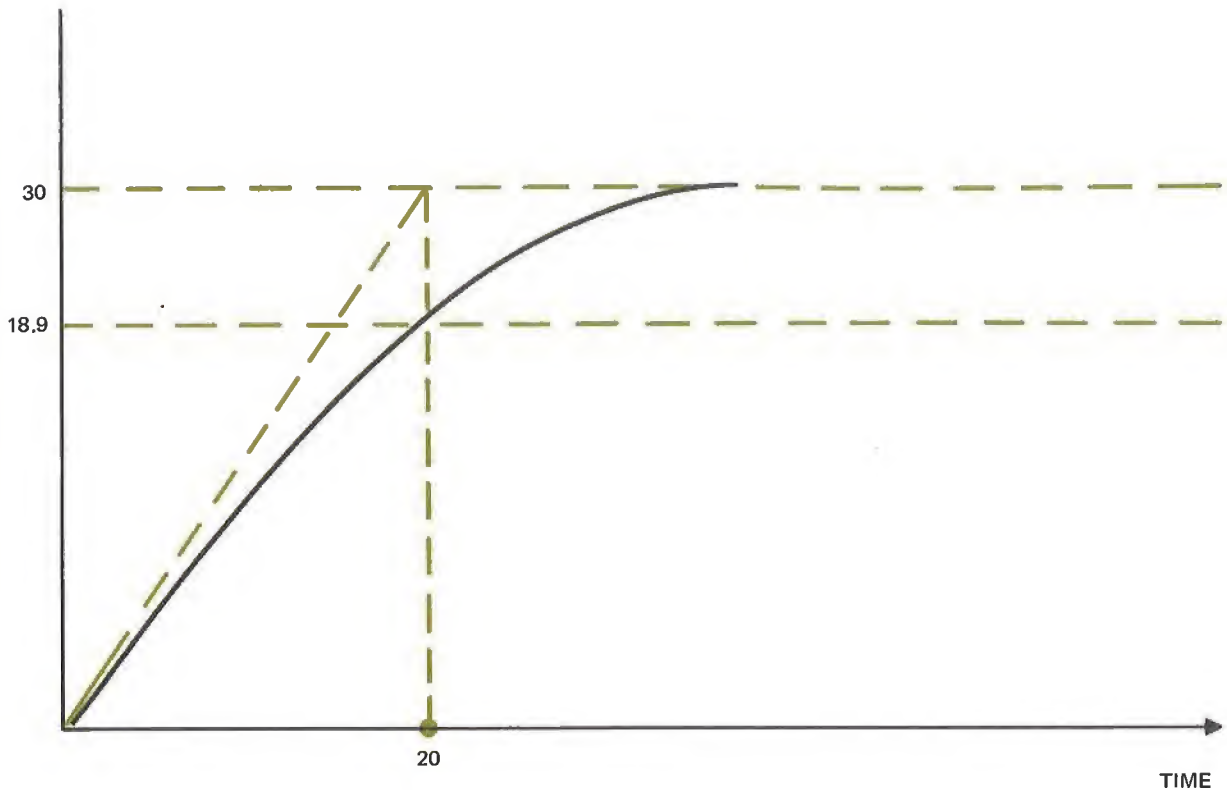


Fig. 7-1 Relative Time Constant

stant and completes 63% of the remaining change during each succeeding time constant, provided a single resistor-capacitor combina-

tion exists. For all practical purposes we can say the system has reached its steady state after five time constants.

MATERIALS

- | | |
|----------------------------|-------------------------------|
| 1 Hydraulic pump unit | 1 Flow control (gate) valve |
| 1 0-600 psi pressure gauge | 1 Flow control (needle) valve |
| 1 Adjustable relief valve | 1 ft plastic hydraulic hose |
| 1 Check valve | 25 ft plastic hydraulic hose |

Assorted fittings and hoses as needed.

PROCEDURE

1. Set up the hydraulic circuit shown in figure 7-2.

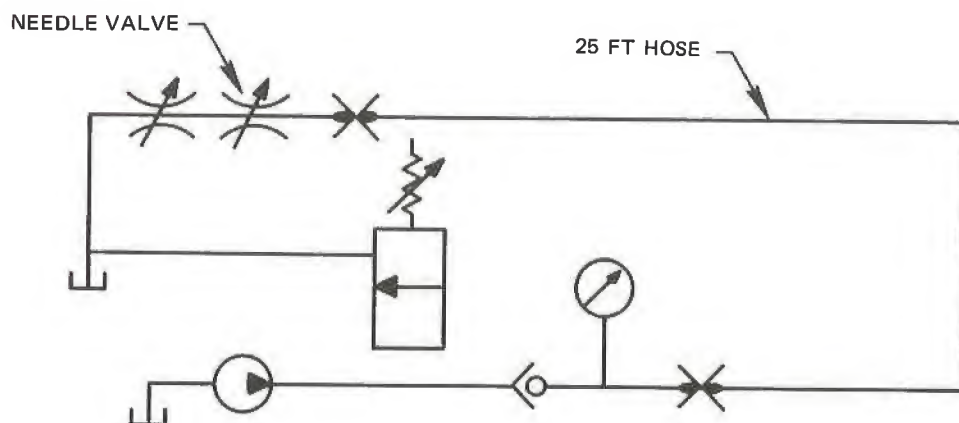


Fig. 7-2 The Experimental Circuit

2. With the needle valve slightly open and the flow control valve fully open, adjust the relief valve so that the pressure reading is approximately 100 psi, then close the flow control valve and adjust until a pressure of 200 psi is attained.
3. Turn off the pump.
4. Quickly open the flow control valve completely and read and record the pressure at intervals of 15 seconds until the pressure goes to zero.
5. Without moving the needle valve, close the flow control valve and start the pump to recharge the system to a pressure of 400 psi by adjustment of the relief valve.
6. Read and record the pressure at 15-second intervals until it goes to zero.
7. Replace the 25 ft hose with a 1 ft hose and again, without moving the needle valve, repeat steps 2-4, with the exception that readings are taken at 5-second intervals.
8. Plot graphs of the three systems on the same set of coordinates.

ANALYSIS GUIDE. In the analysis of this experiment you should calculate the time constant of each system. Compare them and explain the differences among them. Are there experimental errors that might affect the validity of the data? How well has this experiment fulfilled its objective?

25 ft Hose No. 1	TIME (SEC)	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	
	PRESSURE PSI	200																	
	TIME (SEC)	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	
	PRESSURE PSI	400																	
	TIME (SEC)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	
	PRESSURE PSI	200																	
	TIME (SEC)	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	
	PRESSURE PSI	200																	
	TIME (SEC)	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	
	PRESSURE PSI	200																	
	TIME (SEC)	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	
	PRESSURE PSI	200																	

Fig. 7-3 Data Table

experiment 8 PNEUMATIC TIME CONSTANTS

INTRODUCTION. Any change from one pressure level to another in a pneumatic system, as well as in any other system, requires time. In this experiment we will examine the rate of change in a pneumatic circuit.

DISCUSSION. The use of pneumatic systems in industry can be classified into two main groups, *pneumatic power* and *pneumatic control*. Pneumatic power devices are typified by punches, trimmers, lifts, and clamping devices. In general, pneumatic power systems rather than hydraulic systems are used where speed is desired and light loads are involved. If the loads are great and speed is of secondary importance, hydraulic circuits are used.

Pneumatic controls are taking on greater significance every day. They have several advantages over electrical systems, the present principal means of control. Air pilot valves can operate indefinitely without malfunction. These valves will not burn out if overheated and create no fire hazard in explosive areas.

The development of logic control methods is opening new areas for pneumatic control. Logic is a control system's ability to determine an alternate course of action when the course directed proves to be undesirable. Pneumatic logic control occurs through the use of fluids in motion without moving parts. This control field is known as *fluidics*. Fluidic control devices have compact size, low cost, and long life but have response times that are slow compared to sophisticated electronic computer systems. It is the response time of a pneumatic system that this experiment will examine.

If a pneumatic system is subjected to a sudden change of input, it will require a period of time before the system can completely respond to the change. This changing

period is known as a transient *response* condition. When the system has finally reached equilibrium and becomes constant we say it is in its *steady-state* condition.

The transient response of a pneumatic tank being charged can be understood by examination of figure 8-1. As air is forced into the storage tank inlet at a constant rate, it is affected by two things. First, there is a resistance acting upon it caused by the small inlet diameter and the rigid tank walls. These have a tendency to oppose the motion of the air entering the tank. At the same time the large cavity of the tank acts as a capacitance.

When air first begins to come into the tank, the pressure inside the tank starts to increase at a rapid rate. However, as the inside pressure increases, net pressure difference forcing fluid into the tank decreases and thus the pressure climbs at a slower rate. The result is the exponential curve shown at the right in figure 8-1.

If the rate of increase of pressure had remained constant from the beginning, the maximum pressure $P_{\max}$ would have been reached at time τ . But since the rate actually decreases exponentially, only 63% of $P_{\max}$ is reached by time τ . This amount of time is known as the system's *time constant*.

The time constant of a series system like figure 8-1 is directly proportional to the values of resistance and capacitance such that

$$\tau = RC \quad (8.1)$$

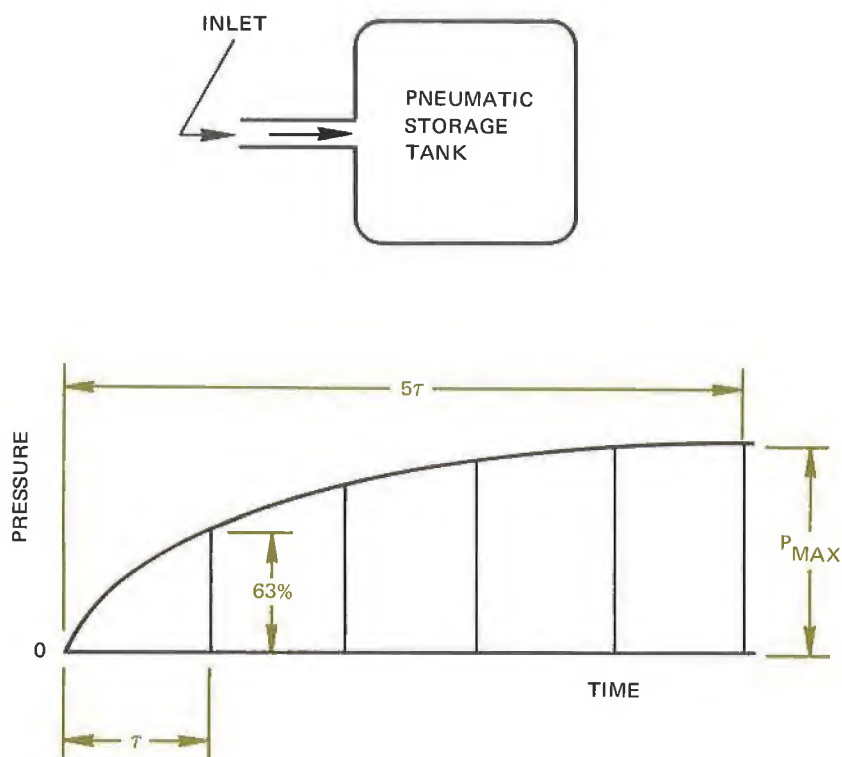


Fig. 8-1 Transient Response Of a Pneumatic System

This value measures how fast the system responds to a disturbance. If τ is large, the system is sluggish and responds slowly. If τ is small, the system responds rapidly.

We can see in figure 8-1 that after one time constant the system has reached 63% of its steady-state condition. In the second time

constant the system reaches 63% of the remaining pressure difference. This continues for each time constant, thus an infinite time is required before the system truly reaches steady-state. However, after about 5 time constants the system can be considered to closely approximate its steady-state condition.

MATERIALS

- 1 Air compressor with storage tank and pressure gauge
- 1 Flow control (needle) valve
- 1 Flow control (gate) valve
- 1 0-120 pressure gauge
- 1 5 ft pneumatic hose

Assorted fittings and hoses as needed

PROCEDURE

1. Drain the pneumatic tank completely using the tank drain plug.
2. Start the compressor and record the pressure readings at the beginning and after each 20 seconds as shown in the table in figure 8-2.

TIME (SEC)	0	20	40	60	80	100	120	140
PRESSURE PSI								
TIME (SEC)	160	180	200	220	240	260	280	300
PRESSURE PSI								

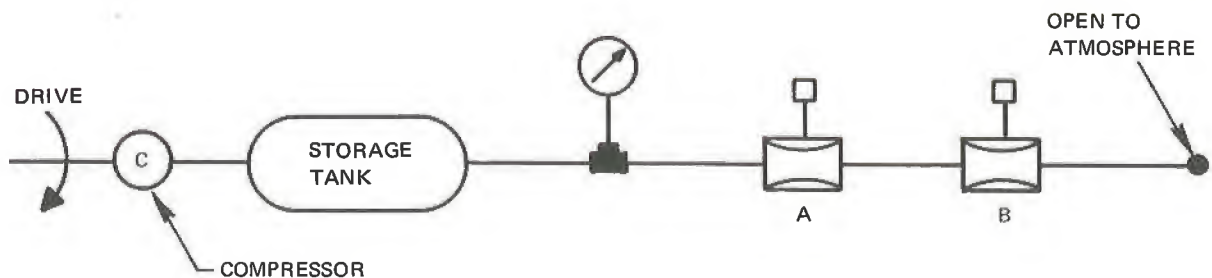
Fig. 8-2 Time-Pressure Table

3. Turn off the compressor, drain the tank using the drain plug, and record the readings after each 20 seconds. Record these data in figure 8-3.

TIME (SEC)	0	20	40	60	80	100	120	140	160
PRESSURE PSI									
TIME (SEC)	180	200	220	240	260	280	300	320	340
PRESSURE PSI									

Fig. 8-3 Time-Pressure Table

4. Set up the pneumatic system shown in figure 8-4.
5. Charge the system to 90 psi.

*Fig. 8-4 Experimental Pneumatic System*

6. With valve B closed, open valve A one-fourth turn.
7. Quickly open valve B and read and record the pressure at 20-second intervals until the pressure reads zero.

TIME (SEC)	0	20	40	60	80	100	120	140
PRESSURE PSI								
TIME (SEC)	160	180	200	220	240	260	280	300
PRESSURE PSI								

Fig. 8-5 Time-Pressure Table

8. Recharge the system to 90 psi.
9. With valve B closed, open valve A one-half turn.
10. Repeat step seven.

TIME (SEC)	0	20	40	60	80	100	120	140	160
PRESSURE PSI									
TIME (SEC)	180	200	220	240	260	280	300	320	340
PRESSURE PSI									

Fig. 8-6 Time-Pressure Table

ANALYSIS GUIDE. Plot a graph of each set of data. Find the corresponding time constants. Are they the same? Do the last two graphs indicate a linear system? Explain your answer.

experiment 9 POWER AND ENERGY IN FLUID NETWORKS

INTRODUCTION. Many systems contain working fluids in motion under pressure. In this experiment we shall examine the basic energy relations of a fluid system and see how power is converted in a hydraulic motor.

DISCUSSION. Energy appears in many different forms. Man has used these various forms to divide physical science into different fields. The electronics field involves electrical and magnetic energy, mechanics and fluids use mechanical energy, thermodynamics involves thermal energy, acoustics concerns sound energy, optics involves electromagnetic energy, and magnetics deals with magnetic energy. We also have nuclear and chemical energy. All of these energy forms have similar properties even though man has chosen to separate them. In addition, each of these forms may be transformed into the other forms. *A major property of energy is its ability to change its form.*

The change from one form of energy to another happens around us all the time. Merely standing in the sunshine lets you feel the change of light energy into heat. A motor changes electrical energy to mechanical energy, a generator changes it back. A loud speaker changes electrical energy to sound. Any device used to change one form of energy to another is called a *transducer*. Even your body acts as a transducer when it changes chemical energy through digestion into heat and mechanical energy or motion; thus we see that all energy, no matter what its form, is basically the same.

Work is a measure of energy transfer. Therefore, energy is measured in the same units as work. The unit of work or energy is the ft.-lb. which is the amount of work done on a one-pound body when it is moved a distance of one foot. We see that:

$$\text{work} = \text{force} \times \text{distance} \quad (9.1)$$

Generally when work is done, we are interested not only in how much but also how quickly it is done. This is measured in terms of *power* which is expressed as work per unit of time.

$$\text{Power} = \frac{\text{Work}}{\text{Time}} = \frac{\text{Force} \times \text{Distance}}{\text{Time}} \quad (9.2)$$

One unit of power is the *horsepower*. Originally known as the amount of work done by a draft horse in one minute, the horsepower is defined differently today. For some of the systems used today the horsepower is defined as follows:

$$\begin{aligned} \text{One Horsepower} &= 33,000 \frac{\text{ft.-lb.}}{\text{min.}} \\ &= 746 \text{ watts} \end{aligned} \quad (9.3)$$

Since this experiment deals with energy in a fluid system, let's consider the pipe section shown in figure 9-1.

A force F is acting upon a cross-sectional area of the fluid in the pipe in the direction indicated. Each tiny bit of this area in the pipe has a portion of the force acting upon it such that the force is uniform over the entire area. The force on one bit of unit area of the total area is known as *pressure*. The pressure is equal to the force divided by the area.

$$P = \frac{F}{A} \quad (9.4)$$

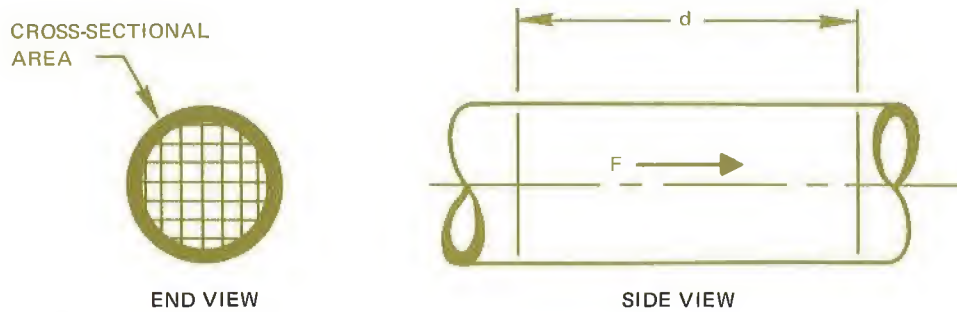
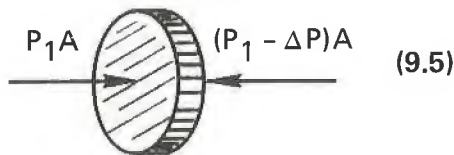


Fig. 9-1 Pipe Section

We can see that pressure has additional significance when we bring energy into consideration. Consider a volume of fluid of area A and thickness 1 in the pipe. If the pressure at the lefthand face is P_1 and that on the righthand face is $P_1 - \Delta P$, then the *net* force pushing this disc-shaped volume of fluid to the right is

$$F_{\text{net}} = P_1 A - (P_1 - \Delta P) A = \Delta P A$$



(9.5)

Since the volume of this disc is $A1$, the net force per unit volume due to pressure is

$$\frac{\Delta P A}{A1} = \frac{\Delta P}{1} \quad (9.6)$$

That is the pressure drop per unit length along the pipe.

If this pressure drop per unit length is uniform (the same all along the pipe), the work done by pressure forces per unit volume as a volume of water moves a distance d along the pipe is the force per unit volume times the distance d . Therefore the work done per unit volume of fluid in this motion is pressure drop per unit length times the distance or ΔP along the distance d . The work done per unit volume of fluid in moving fluid from a point

where the pressure is P_1 to a point where the pressure is P_2 is equal to $(P_1 - P_2)$.

Fluid flow rate measures the quantity of fluid passing a given point per unit of time. If, in a given time, a quantity (volume) of fluid V crosses an area A , then the volume flow rate Q is defined as

$$Q = \frac{V}{t} \text{ in.}^3/\text{sec or gal/min} \quad (9.7)$$

Q is directly comparable to electric current which is the rate of flow of electric charge for incompressible fluids.

In a dynamic system one of our primary concerns is that of power. Power is the rate of doing work. Hence the power input to fluid moving from a place where the pressure is P_1 to a place with pressure P_2 is work per unit volume times volume per unit time, i.e., $(P_1 - P_2)Q$.

Thus, the net power delivered to a two-terminal element is

$$P_o = Q (P_1 - P_2) \quad (9.8)$$

or power = flow rate times pressure difference.

In this experiment we will examine the power required to turn a hydraulic motor and then measure the power output of the motor, thus finding its efficiency.

MATERIALS

- | | |
|----------------------------|---------------------------------------|
| 1 Hydraulic pump unit | 1 Flow meter |
| 1 Adjustable relief valve | 1 Hydraulic motor |
| 1 Flow control valve | 1 Dynamometer |
| 2 0-300 psi pressure gauge | Assorted fittings and hoses as needed |

PROCEDURE

1. Set up the hydraulic system shown in figure 9-2. Be absolutely sure that the hoses are in good repair and all of the hose clamps are tight. High pressures will be developed while loading the hydraulic motor in this experiment.

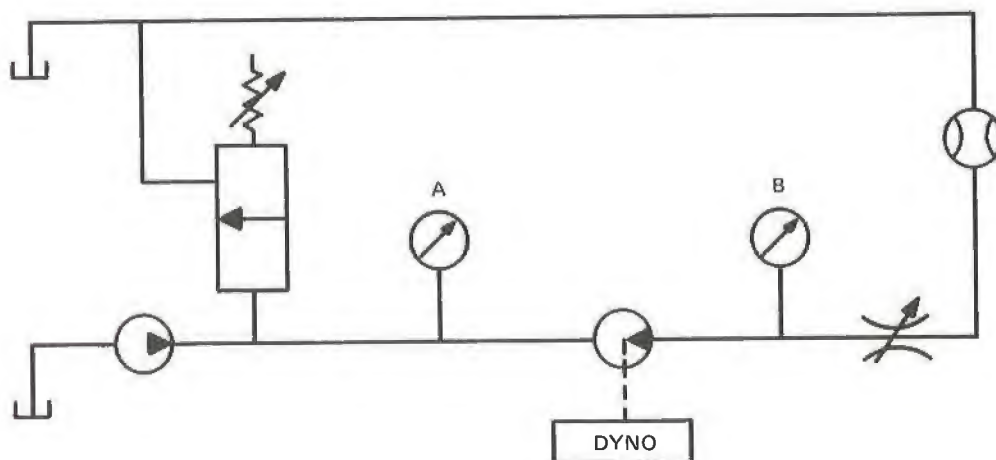


Fig. 9-2 Experimental Hydraulic Network

2. With the relief valve backed off and the flow control valve open, start the pump.
3. Adjust the relief and flow control valves to allow a flow of 1 GPM at a pressure of 100 psi at gauge A with no load.
4. Read pressure gauge B and subtract its value from that of gauge A to determine the pressure drop due to the resistance of the motor. Record this drop in the data table.
5. Using the dynamometer, load the motor and record the torque delivered by the motor at the RPM attained just before it stalls. At this point also record the flow rate and pressures A and B. Calculate the power into the motor, power out of the motor and motor efficiency.

NO LOAD SETTING									
PRESS. A	FLOW RATE	PRESSURE A	PRESSURE B	FLOW RATE	POWER IN	RPM	FORCE IN POUNDS	POWER OUT	MOTOR EFF
100	1								
150	1								
200	1								
250	1								
300	1								
200	1.5								
200	2.0								
200	2.5								
200	3.0								

Pressure drop due to motor resistance with no load.

Fig. 9-3 The Data Table

6. Keeping the flow constant at 1 GPM, increase the pressure A with no load in steps of 50 psi up to 300 psi.
7. Repeat steps 4 and 5 for each value of pressure.
8. Keeping the pressure at gauge A constant at 200 psi with no load, increase the flow in steps of 0.5 GPM to 3 GPM.
9. Repeat steps 4 and 5 for each increment.
10. Plot graphs of the power into the system versus efficiency and the power out of the system versus efficiency.

ANALYSIS GUIDE. In this experiment we have observed fluid power losses. Discuss the variables involved, identify the losses, and elaborate upon the efficiency with respect to pressure and flow rate as seen in this network. In your own words, explain the relations of energy, power, work, force pressure, torque, and volume as related to fluid power systems of the type in this experiment.

PROBLEMS

1. The oil in a system is being moved at 12 GPM while the pressure is 1500 psi. What horsepower is being delivered?
2. A man unloads steel stock from a flatbed truck to a cart, a vertical drop of 4 feet. He unloads one ton of steel in one hour's time. Calculate the work done and the power used in horsepower.
3. What horsepower motor will be required to drive a hydraulic pump handling 100 GPM of fluid at a pressure of 3000 psi?
4. A mechanic tries unsuccessfully to loosen a nut. He exerts a force of 70 lb on the wrench handle which is 18 in. long. What torque is exerted and what work is done?
5. What is the power exerted by a hydraulic motor to produce a speed of 1380 RPM with a force of 12 lbs acting tangentially at a radius of 6 inches?

experiment 10 KINETIC ENERGY STORAGE IN FLUID SYSTEMS

INTRODUCTION. The fluid moving in a fluid network possesses energy due to its motion. The objective of this experiment is to examine this kinetic energy.

DISCUSSION. Many systems contain working fluids in motion under pressure. These hydraulic systems are utilized in industry to perform many functions. Hydraulic presses, mills, cutters, and punches are common examples. Hydraulic systems are used in automobiles in their braking and transmission systems. All of these functions do work and, therefore, must involve the transformation of energy.

The energy of a fluid system is mechanical energy, potential and kinetic. These types of energy can be associated with two characteristics of the network, which we shall call *capacitance* and *inertance*. In addition, another property is also always present. This property is *resistance*, which does not contribute to the storage of energy, but to its dissipation. The amount of each of the three properties present in any one system determines the energetic processes that occur within the system.

Fluid capacitance is the property of a system that determines its ability to statically

store potential energy. This type of storage depends on the pressure of the system. If the system shown in figure 10-1 is subjected to a pressure at the inlet, the initial effect is capacitive.

As the fluid enters the tank it encounters less resistance than in the inlet because the cross-section has enlarged greatly. If the valve is partially closed, the tank is eventually filled. Then if the valve is closed completely, the pressure in the tank is equal to the same pressure as that in the line. If at this point we stop the supply of fluid into the inlet and not let it flow backwards, the fluid in the tank is under pressure. The tank, like an electrical capacitor, now has statically stored an amount of energy. We can show this by opening the valve and seeing that work is done by turning the hydraulic motor until the pressure drops to zero. This stored energy is the result of compressing the fluid. We see, then, that an ideally incompressible fluid cannot store potential energy, i.e., there would be zero fluid capacitance.

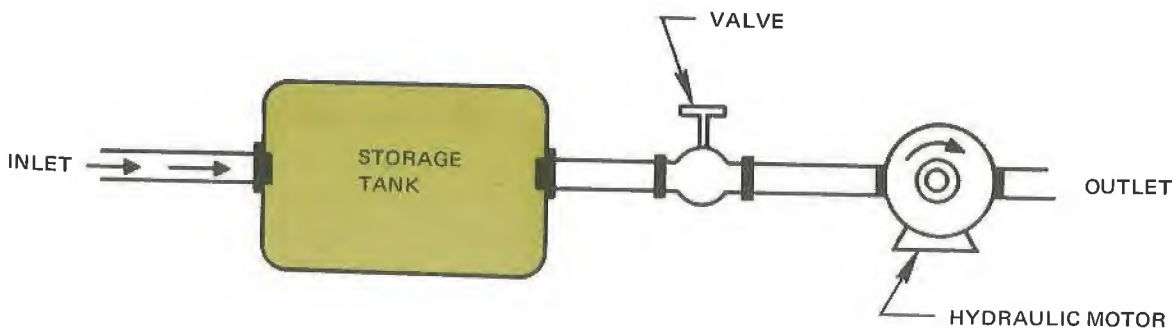


Fig. 10-1 Fluid Capacitor

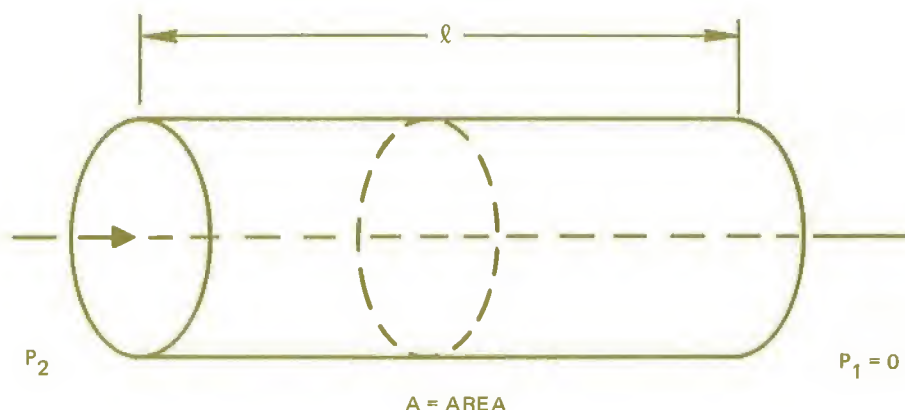


Fig. 10-2 Acceleration of Fluid Flow in a Pipe

Fluid inertance is the property of a system which determines its ability to store kinetic energy. Inertance is of importance in fluid motion or flow. Just as a moving automobile has a momentum which keeps it moving when power is removed, so does fluid in a pipe. This momentum is proportional to inertance. The length of pipe shown in figure 10-2 will help us in understanding fluid inertance.

The mass of fluid in a length ℓ of a pipe is the pipe area (A) times its length (ℓ) times the density of the fluid (ρ).

$$m = A \ell \rho$$

Therefore, the kinetic energy of this mass of fluid is

$$K E = \frac{1}{2} m v^2 = \frac{1}{2} \rho \ell A v^2 \quad (10.1)$$

The velocity of fluid in a pipe is the flow rate divided by the area,

$$v = \frac{Q}{A} \quad (10.2)$$

so that the kinetic energy given by equation

(10.1) can be written in terms of the flow rate Q as

$$K E = \frac{1}{2} \rho \ell A \frac{Q^2}{A^2} = \frac{1}{2} \left(\frac{\rho \ell}{A} \right) Q^2 \quad (10.3)$$

We call the quantity $\frac{\rho \ell}{A}$, the inertance (I) of the system

$$I = \frac{\rho \ell}{A} \quad (10.4)$$

so that the fluid kinetic energy becomes

$$K E = \frac{1}{2} I Q^2 \quad (10.5)$$

From equation 10.4, we see that the inertance of a fluid network is dependent upon the type of fluid and the dimensions of the pipe. A small diameter, long pipe may have more inertance than a large short pipe.

In actual fluid piping, significant resistance effects are present along with the inertance effect. The inertance effect tends to pre-

dominate only when the pressure changes needed to accelerate the fluid (when the pipe changes its cross-section) are relatively large. Since fluid resistance in a pipe decreases more rapidly with increasing pipe area than does inertance, it is easier for inertance effects to overshadow resistance in large pipes. However, if fluid acceleration is large enough, inertance effects can be seen even in small capillary tubes.

There are four basic types of fluid resistance that are the most frequently encountered; (a) porous resistance like an automobile oil filter, (b) capillary tube, (c) turbulent pipe flow, and (d) orifice flow. All of these resistances have some unique features

but they all follow the basic resistance pattern,

$$R = \frac{(P_2 - P_1)}{Q} \quad (10.6)$$

where

R = fluid resistance

$(P_2 - P_1)$ = pressure drop from pressure 2 to pressure 1

Q = flow rate

All three of these types of resistance are found in fluid flow and occur in various applications.

In this experiment we will measure the kinetic energy stored in a fluid network.

MATERIALS

- 1 Hydraulic pump unit
- 1 Solenoid-actuated valve
- 1 Flow meter
- 1 Adjustable relief valve
- 1 1 k Ω resistor
- 1 6 k Ω resistors
- 1 0-600 psi pressure gauge
- 1 25 ft hydraulic hose
- 1 Hydraulic motor
- 1 DPST switch
- 1 DC power supply

- 2 Strip chart recorders
or 1 dual-channel recorder

Assorted fitting and hoses as needed

PROCEDURE

1. Set up the system shown in figure 10-3.

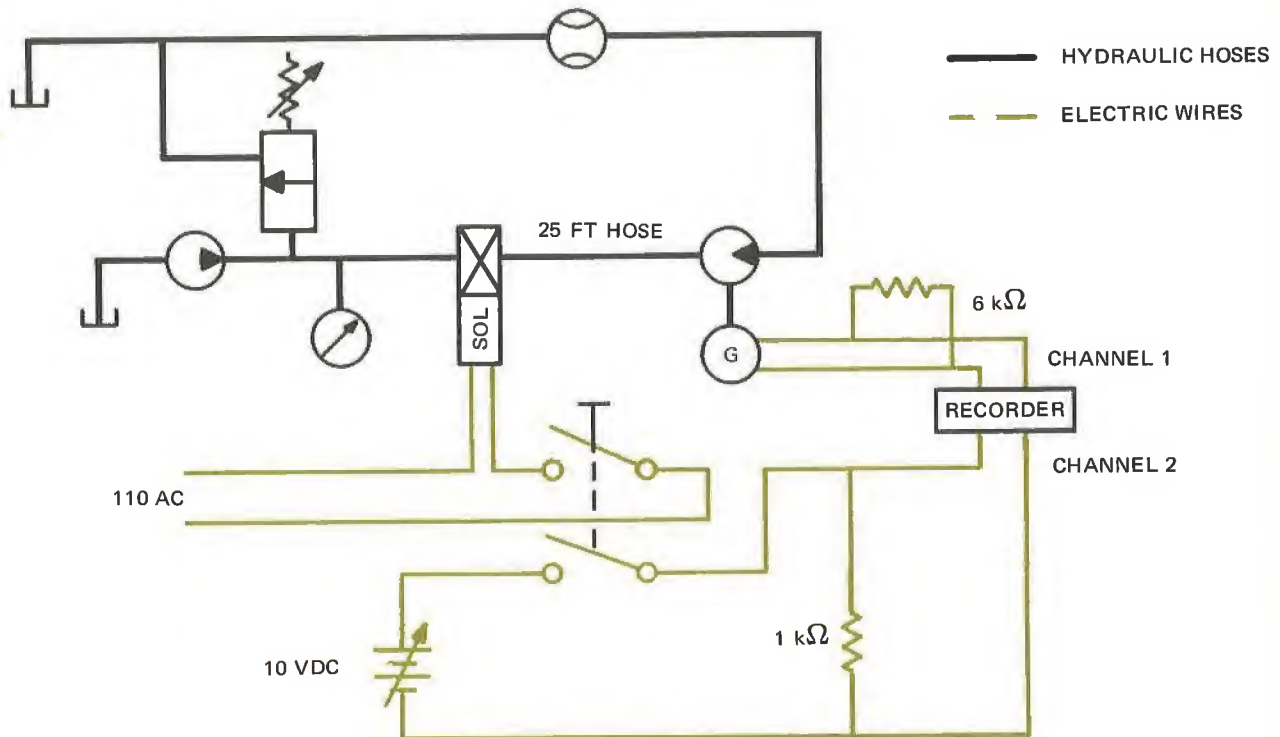


Fig. 10-3 The Experimental System

2. Place the switch in the position to deactivate the solenoid, thus allowing fluid to pass through the motor. With the motor running, adjust the relief valve to a pressure of 100 psi.
3. Record the flow at this pressure in the data table in figure 10-4 and calculate the inertance of the 25 ft hose. Density of hydraulic fluid at room temperature = 56.9 lb/ft^3 .
4. Using equation 10.1, calculate the kinetic energy of the fluid in the 25 ft hose and record it.
5. Calibrate and position the recorder, turn on the D C power supply and start the chart trace.
6. Throw the DPST switch and run the recorder until the hydraulic motor stops.

7. Stop the recorder, throw the DPST switch to allow fluid to flow, and change the pressure setting to 200 psi.
8. Repeat steps 3 through 6.
9. Repeat step 7 for a pressure of 300 psi and then repeat steps 3 through 6. This will give three chart traces in all.
10. Plot power versus time for each pressure measured. Your curves are volts versus seconds. In order to plot power versus time you must square the voltage and divide by your $6k\Omega$ resistance.

PRESSURE PSI	FLOW	CALCULATED ENERGY	MEASURED ENERGY

Fig. 10-4 The Data Table

ANALYSIS GUIDE. In the analysis of this experiment you should determine the kinetic energy stored in the hose by finding the area under the power curve.

Compare the measured and calculated values and explain any differences. Explain the relation of inductance, capacitance, and resistance in the experimental network.

experiment 11 HYDRAULIC MATCHING

INTRODUCTION. In all dynamic systems the load must be compatible with the system output. In this experiment we shall examine a method of matching load characteristics to those of a system output.

DISCUSSION. In almost any system, if it is to function efficiently, the load and output capabilities at any and all points must be compatible. That is, the output characteristics of one device or part of a system must be suitable for those of the input to the next part. The degree to which these conditions are met determines the quality of performance and effectiveness of the system. There may be many different places or points within any single piece of equipment where these conditions of compatibility must be established if the optimum output is to be obtained.

There are some situations of a vastly different nature where it is not desired to transfer the maximum amount of energy. Rather, the situation may require that there be NO transfer of energy because if there were, the conditions in which we were interested and wished to observe would themselves be changed by the transfer. For example, if a thermometer requires a significant amount of heat flow into it to make it register, the ambient temperature will be reduced which will result in an erroneous reading. One of the major problems in making any measurements is that of having the measuring device alter the situation. In order to make the concept of *matching* more meaningful, let us consider some examples.

Each time one of us drives an automobile, the matter of steering is involved. Because of the weight of the car and the location of the engine, the front wheels usually carry most of the load, so a rather large force is required to

turn them. Also, most drivers can develop relatively small forces. It is not possible to apply the required forces directly to the wheels.

Our major problem is to match the requirements of steering or turning the wheels with reasonable forces which can be developed by the average driver. The front wheels need be turned only a limited amount, but the load on them is such that the torque required to provide the turning is beyond the average person's capabilities. The ordinary driver, on the other hand, can develop a reasonable force of several pounds and he is not particularly restricted as to the distance through which he can develop the force. Thus, we are in the position of being able to exert at least some force on something that moves through a reasonably large distance. Our task then is to match the machine to the driver.

This requires that we interpose some other device or system between the wheel which the driver manipulates and the output turning of the front wheels. We must also first recognize that certain adjustments can be made by selecting the size of the steering wheel—for limited turning, the larger the wheel, the easier the turning. But a large steering wheel may require such extended turning as to be tiring to the driver or result in wheel movement which is too slow to be practical with modern speeds. The intermediate device which we use is, of course, a gear train with which we can trade distance for force. The product of the input force and the input dis-

tance which the steering wheel moves equals the produce of the output force and the output distance. Except for small friction effects, this is the conservation of energy. In this manner the output capabilities of the driver are matched to the requirement of the car.

The brakes on a car present problems similar to those of the steering situation. Large forces must be applied to the brake shoes if they are to create retarding forces adequate for stopping a vehicle within a reasonable time or suitable distance.

Vehicle operators, however, are limited in their ability to exert force on brake pedals. Thus, for satisfactory operation, we need some suitable force amplifier so that we can put in a small force and create at the brakes the larger forces which will accomplish the desired result. This is another example in which the available forces (from the operator) do not match the requirements of the machine. We must interpose between the operator and the brake drum, some device or element which will match the available forces and movements to those required to stop the vehicle.

While the forces applied to the brake shoes may be great, this force actually moves the shoe a very short distance. The operator, however, can exert the desired force through several inches if necessary. Thus, we might trade distance for force.

By choice of appropriate cylinder diameters and lengths, we can match the inputs to the forces and travel which are required at the brake shoes. The brake mechanism, either hydraulic or mechanical, provides for a conversion of small input force and relatively large distance to the required large output force but relatively small application distance.

Obviously, there is no single solution which will be unequivocally best. In a practical case, there will frequently be a need to make compromises in order to achieve the best overall results.

The general equation which we will use to match an external force with the internal pressure of a fluid system is

$$P = \frac{F}{A} \quad (11.1)$$

when

P = Pressure in the lines, psi

F = External force applied to the system, lbs.

A = Area on which the pressure P is applied in.²

This basic equation is a useful tool for designing a hydraulic circuit. For example, if we were given a certain fixed external load F to lift, and a fixed diameter cylinder, we could calculate the minimum pressure in order to lift the load F.

For example, suppose we are given a weight of 100 lb. and a cylinder diameter of 1 in. Let's calculate the minimum pressure required to lift the weight.

a) $F = 100 \text{ lb.}$

b) $A = \frac{\pi D^2}{4}$

$$A = \frac{\pi (1)^2}{4}$$

$$A = 0.785 \text{ sq. in.}$$

c) $P = \frac{F}{A}$

$$P = \frac{100}{0.785} = \frac{\text{lb.}}{\text{sq. in.}} = 127 \text{ psi}$$

In actual practice the pressure will have to exceed 127 lb/sq. in. in order to raise the force because of internal resistance in the lines, fittings, valves, etc. If we were to replace the 1-in. diameter cylinder with a 2-in. cylinder, we could reduce our 127 lb/sq. in. by $\frac{1}{4}$ because we have increased the piston area by four.

$$\frac{P_2}{P_1} = \frac{A_1}{A_2} \quad \text{where } F \text{ is constant} \quad (11.2)$$

Using the values above in this equation gives us

$$P_1 = 127 \text{ lb/sq in}$$

$$A_1 = 0.785 \text{ sq in}$$

$$A_2 = \frac{\pi D^2}{4} = \frac{\pi (2)^2}{4} = 3.14$$

$$P_2 = \frac{P_1 A_1}{A_2} = \frac{(127)(.785)}{(3.14)}$$

$$P_2 = 31.8 \text{ psi}$$

This result verifies that P_2 is indeed $\frac{1}{4}$ of P_1 if the cylinder diameter is doubled.

If we want to raise the force through a certain distance, we must use the following equation

$$\text{work} = \text{force} \times \text{displacement} \quad (11.3)$$

As an example, suppose we are given

$$\text{Force} = 100 \text{ lb}$$

$$\text{Displacement} = 1 \text{ ft}$$

then

$$W = F \times D$$

$$W = (100) \times (1) = 100 \text{ lb-ft}$$

With this result we can use equation (11.4) to calculate the horsepower needed to do the job in one minute.

$$\begin{aligned} \text{H P} &= \frac{\text{work in one second}}{550 \text{ lb-ft}} \\ &= \frac{\text{work in one minute}}{33,000 \text{ lb-ft}} \quad (11.4) \end{aligned}$$

$$\text{H P} = \frac{\text{ft-lb per minute}}{33,000} = \frac{.100}{33,000}$$

$$\text{H P} = 0.00303$$

In fluid circuits we must go one step further and calculate the gallons per minute required to obtain this value of the horsepower. For values in the low and medium pressure ranges (up to 1,500 psi), gear pumps are the most commonly used type. Their volumetric efficiencies are high (95%) and so are their mechanical efficiencies (90%). Since gear pumps have been the most common type used in hydraulic systems, it is worthwhile to have some idea of the size of the gears, capacities, and horsepower for these units. For standard involute gears, the theoretical rate of flow from a gear pump can be computed by the following formula.

$$Q = \frac{D_o^2 - D_i^2}{4(231)} \pi L N \quad (11.5)$$

where Q = theoretical delivery rate, GPM

D_o = outside diameter of the gear, in.

D_i = working depth diameter of the gear, in.

L = width of the gear, in.

N = rotating speed of the pump, RPM.

The hydraulic flow rate, GPM, at a certain rated horsepower can be obtained using

$$Q = \frac{HP (1714)}{P} \quad (11.6)$$

where Q = flow rate, GPM

P = discharge pressure, psi

In our previous example the required GPM would be

$$Q = \frac{HP (1714)}{P} = \frac{0.00303 (1714)}{(31.8)}$$

$$= 0.163 \text{ GPM}$$

In order to find the number of revolutions per minute that must be applied to the pump

by a motor, we could use equation 11.7.

$$RPM = \frac{HP (33,000)}{(2\pi) (\text{torque})} \quad (11.7)$$

The torque can be determined by

$$T = \frac{DP}{24\pi} \quad (11.8)$$

where D = displacement of pump in cu.in. per revolution

P = difference in pressure, psi

At this point the calculations would be completed. Notice that the load would be matched to the pump and the pump would be matched to the motor.

MATERIALS

- | | |
|---|-----------------------------|
| 1 Hydraulic bench unit | 10 5 lb weights |
| 1 Relief valve | 1 Stopwatch |
| 1 1½" dia. x 5" stroke hydraulic cylinder | 1 Pressure gauge (0-50 psi) |

PROCEDURE

1. Set up the hydraulic circuit shown in figure 11.1.

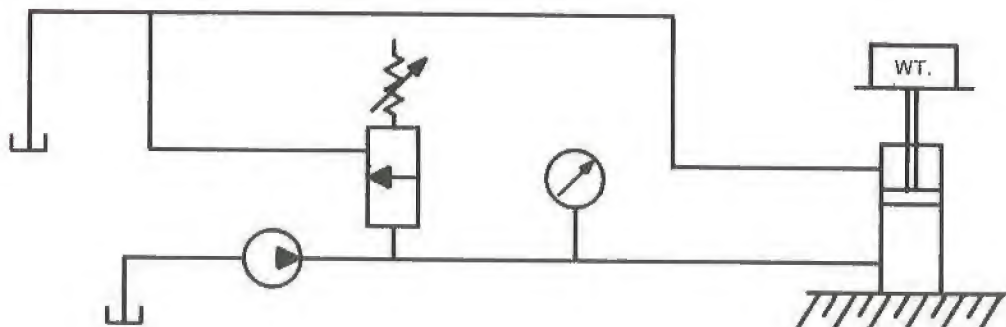


Fig. 11-1 Experimental Circuit

2. Start the pump and adjust the pressure to 50 psi using the relief valve.
3. Switch hoses on the cylinder to force the piston to the bottom.
4. With the pump off, switch the hoses back to the original position.
5. With no weight on the piston, turn on the pump and measure and record the time required for the piston to extend completely.
6. Repeat steps 3 through 5 adding weights in 5-lb steps until you have data for loads from 0 to 50 lbs.
7. Calculate the power required to raise the weights at each 5-lb step.
8. Plot a graph of load versus power.

WEIGHT (lbs)	TIME (sec)	POWER (lb -ft/sec)
0		
5		
10		
15		
20		
25		
30		
35		
40		
45		
50		

Fig. 11-2 The Data Table

ANALYSIS GUIDE. In the analysis of these data you should explain the curve plotted in step eight. Which load matched the internal impedance of the system best? Why? What factors might affect the validity of the data?

PROBLEMS

1. Calculate the total work done in the entire experiment using equation 11.3.
2. Using equation 11.4, calculate the minimum H P needed to do the work in problem 1 in one minute.
3. What must be the minimum psi of a hydraulic system in order to raise a 75-lb weight 10 ft with a 2 in. dia. cylinder in 30 seconds? What is the HP? What is the GPM required?

experiment 12 THERMAL MATCHING

INTRODUCTION. Many examples of thermal matching are to be found in everyday life. In this experiment we will match the output of a thermal system to its load.

DISCUSSION. Thermodynamics, the study of energy transformation involving thermal energy and heat flow, has had a long and interesting history. It was necessary at the start of the Industrial Revolution when it became important to understand the relation between heat and chemical reactions and the conversion of thermal into mechanical energy.

It was natural for the early investigators of thermal phenomena to think of "heat" as a fluid, something like a gas or like the "electric fluid" which was being considered at about the same time. Temperature was then thought of as something analogous to a pressure, being proportional to the quantity of heat fluid contained by the body and inversely proportional to the heat capacity of the body. To put it quantitatively, an addition of an amount (Q) of heat to a body will raise its temperature by an amount (ΔT) equal to the heat capacity of the body ($1/C$) multiplied by the quantity.

$$\Delta T = \frac{Q}{C} \quad (12.1)$$

The tendency of bodies to reach thermal equilibrium is thus equivalent to the tendency of heat to flow from a region of higher temperature to one of lower.

That this picture of heat as a fluid is more or less self-consistent was shown by the fact that heat can be produced in several ways: by sending an electric current through the body, if it is metallic, or by producing a chemical reaction in it, such as the burning of a mixture of fuel and air. A given current, or the

burning of a given amount of fuel, produces a small increase of temperature in a large body or a large increase in a small body, so it is consistent to consider that the burning of a given amount of fuel produces a given amount of heat. Within certain limits, this picture of heat is a satisfactory model for representing thermal behavior.

Having gone this far, the temptation was great to give the entity, heat, other properties of a fluid, such as inertia and velocity. The rate of flow Q , of heat, by conduction through a body per second per unit area, turns out to be proportional to the temperature change times a constant K , where K is the *thermal* conductivity of the material.

This relation is represented symbolically by

$$Q = K\Delta T \quad (12.2)$$

The thermal conductivity of a material is its ability to conduct heat. We are interested in conductivity and in the opposite of conductivity — resistance. We can rearrange the above relation and combine it with the equation (12.1) to give us a relation for resistance to heat flow.

$$R = \frac{\Delta T}{Q} \quad (12.3)$$

It was natural for the early investigators to develop this concept of heat as a fluid and temperature as its pressure. They naturally went on to assume the amount of heat contained by a system in *equilibrium* had inertia and velocity. Heat, however, does not turn out to have these properties of a fluid. It has been demonstrated that it is possible to obtain an unlimited amount of heat flow from a

system, provided only that mechanical work was done to the system. "Heat", then, or better, "thermal energy", is not a separate entity but merely a form of energy that can be changed into other forms such as electrical or mechanical energy.

The heat transfer, like the transfer of other energies, is quite often critical to the operation of a system. We find that consideration must be given to the choice of elements which will be used for the transfer of heat. We must determine from the apparatus design or application, those factors which will facilitate the most efficient transfer of heat from the emitting source to the absorbing device.

As an example, if we place a 10-inch frying pan over a heating unit with an effective diameter of 4 inches, there will be a large portion of the pan which is accomplishing relatively little. On the other hand, if we place a pan of four-inch diameter on a heating unit which has an effective diameter of 10 inches, a large portion of the heat which is generated will not be transferred to the vessel. In each case, there is not an effective coupling of the heating device to the pan. Providing the most efficient transfer of heat in terms of the BTU's per minute, or BTU's per second, requires that the heat-absorbing characteristics of the pan be matched with the thermal generating characteristics of the heater. In this case, we must match output and input characteristics by choice of size or by the manner in which the absorbing vessel contacts or fits the heating element. For any given size of heating element, there will be a size of vessel which will absorb the maximum amount of heat.

Another type of heat-absorbing problem might involve the design of a gas water-heater. Experience has shown that certain recovery rates are desired which in turn determines the rate at which the gas must be burned to maintain a desired amount of hot water. Let us

assume, for our example, that the burned gases are to pass through a four-inch long metal tube and in this manner transfer heat to the water. Let us now go to the other extreme and make the heat-exchange tube 10 feet long. This is an impractical design for a heater because it would not fit into many houses, but it might be highly efficient. However, we might find that most of the heat is absorbed in the first four feet of absorbing material and that all of the rest of the tube actually contributes relatively little. This would be the case if the hot, burned gases by then had already been reduced in temperature to the point where they could transfer almost no heat to the water. Thus, we see that here are two extremes—neither of which is an optimum situation. If most of the heat is transferred in the first four feet of tubing, we could make a heater with only this amount of heat transferring material.

Our task here is to match the heat-absorbing capabilities of the water-heater with the heat generated by the burned gas if we are to have a reasonable thermal efficiency. In the previous example we matched the output of the burned gas to the absorbing characteristics of the device by varying the length of the tubing. Had we started with a smaller diameter of tube, we might have found quite a different answer. However, there must be enough cross-sectional area to permit the products of combustion to pass up through the flue. This precludes using a very small tube which also might be unable to transfer the required amount of heat per unit of time with the available temperature differentials. Thus, there is an optimum area which will transfer the desired amount of heat with the available temperature differential. In this way the design of the device is varied to produce the maximum rate of heat absorption for some given input.

The problem of matching the heat-absorbing material of the gas water-heater to the heat liberated by the flame is comparable to the thermal transfer problem involved in cooling an internal combustion engine found in an automobile.

From the power to be developed by the engine, we can determine the heat which is likely to be transferred to the cooling water. The cooling system must be designed for the maximum load conditions. Inasmuch as the rate at which heat is transferred from the cooling water to the surrounding air varies with the temperature difference, the most difficult cooling conditions will probably be found in the hottest weather of summer. At this time there is the smallest temperature difference between the water and the air. It is this condition, along with some assumed car speed, which is used to determine the size of the radiator.

As an example, let us assume some exposed cross-sectional area and given thickness of the core through which the cooling air must pass. If the exposed area is made very small, the temperature of the cooling water must rise in order that there be a sufficient thermal radiant to transfer the heat to the passing air—the greater the temperature difference, the greater the rate of heat transfer, all other factors being equal. If, on the other hand, we use a radiating element with 20 times the previous exposed area, then the water will be cooled so much that only a small amount of the water in the block is allowed to circulate through the radiator. Obviously, the ideal solution lies somewhere between these extremes. Again, for optimum performance, it is necessary to match the cooling requirements of the engine with the cooling capabilities of

the radiator. This requires that the thermal input to the radiator match the thermal output of the engine.

The matching is sometimes done to achieve the maximum transfer of power. In the case of thermal systems, the rate of flow of heat (Q/t) is equal to the power (P).

$$Q/t = P \quad (12.4)$$

The power being transferred in a thermal system is simply the rate of flow of heat. Figure 12-1 shows a heat transfer system. If a constant temperature heat source is in contact with a block of material, the flow rate (Q) into it is:

$$Q = \frac{K A t \Delta T}{d} \quad (12.5)$$

where

Q = flow quantity in BTU s

K = thermal conductivity of the block in BTU/(ft² hr °F/in.)

A = area in ft²

t = time in hours

ΔT = temperature difference in °F ($T_2 - T_1$)

d = length in inches

This equation may also be used to determine the power being transferred.

In this experiment we will match the use of different aluminum masses in order to achieve maximum power transfer from a heat source.

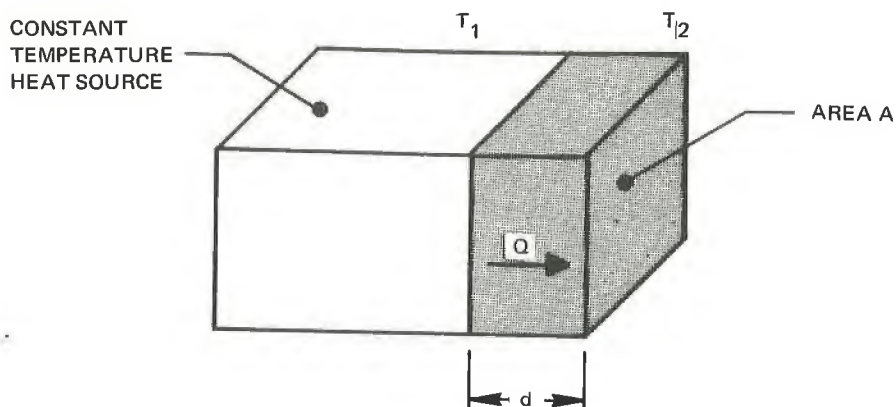


Fig. 12-1 Heat Transfer System

MATERIALS

- | | |
|--------------------|--|
| 1 Bunsen burner | 2 3/4 x 3/4 x 3/4 in. aluminum blocks |
| 1 Ring stand | 1 3/4 x 3/4 x 3/8 in. aluminum block |
| 1 Screen 6 x 6 in. | 1 3/4 x 3/4 x 3/16 in. aluminum block |
| 1 Pair of tongs | 1 3/4 x 3/4 x 1 1/2 in. aluminum block |
| 1 Stop watch | Water for cooling |

PROCEDURE

1. Set up the heat transfer system shown in figure 12-2.

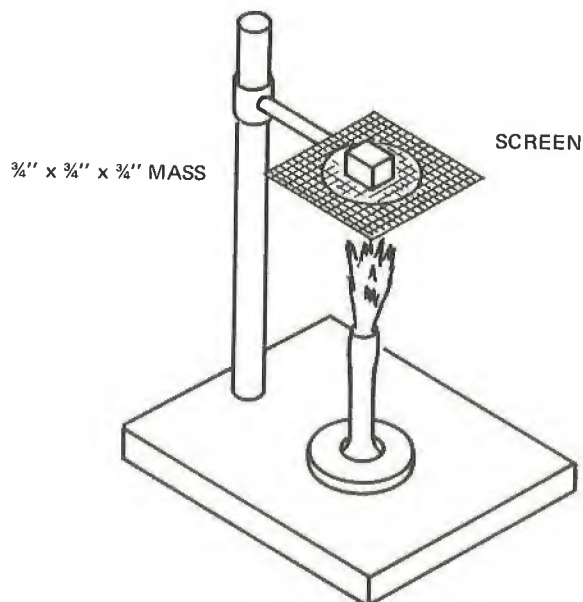


Fig. 12-2 Heat Transfer System

2. Determine and record the temperature of the mass before heating it.
3. Light the burner and heat the mass for 5 minutes to allow it to reach constant temperature.
4. Place a large drop of water on the top surface of the smallest mass and place it on the heated mass. Measure and record the time required to bring the water drop to boiling temperature. Be certain that the *complete* 3/4" surface of the mass is contacting the heated source mass. Cool the mass and repeat the reading three times for accuracy.
5. Repeat step 4 for each of the other masses.
6. Calculate the amount of power required to bring the top surface of each mass to the temperature of the source mass. Thermal conductivity of aluminum $1.5 \times 10^3 \text{ BTU}/(\text{ft}^2 \text{ hr}^\circ \text{F/in.})$.
7. Plot a graph of the heat velocity versus the length of the mass. (*Note: Since the same amount of heat is needed to boil the waterdrop each time, we are interested in the distance/time required. This velocity times Q is power.*)

ANALYSIS GUIDE. In the analysis of this experiment you should determine which mass matched the source block to give maximum energy transference. Explain why. Explain any factors which might contribute to errors in this experiment.

Initial Temperature of masses (T_1) _____					
	TIME				
MASS SIZE	1	2	3	AVERAGE	POWER REQUIRED (Q/t) (d)
3/4 x 3/4 x 3/16 in.					
3/4 x 3/4 x 3/8 in.					
3/4 x 3/4 x 3/4 in.					
3/4 x 3/4 x 1 1/2 in.					

Fig. 12-3 The Data Table

experiment 13 SOUND WAVES IN AIR

While resonance effects in gases are useful in many cases, there are times when they are quite unwelcome. In this experiment we will examine the phenomenon of resonance and measure the velocity of sound in air.

The phenomenon of the relatively large amplitude of vibration of a system when driven by a small periodic force applied at proper time intervals is known as *resonance*. Resonance may occur in any system capable of vibrating by itself. Perhaps the best way to illustrate the idea of resonance is to give some examples. Suppose a ball is suspended by a wire from a point P and a light thread is attached to the ball at C as shown in figure 13-1. By itself it is a pendulum and can oscillate with a definite period. The tiny force

the thread can exert without breaking will displace the ball a very small distance. When the force is removed, the ball swings back to the left beyond its rest position. If the force is again applied while the ball is going to the right, the ball will attain a second displacement slightly greater than its first one. You may recall when, as a child, you were being pushed in a swing. At just the right time you were given a boost and went higher than the previous time. These are examples of mechanical resonance.

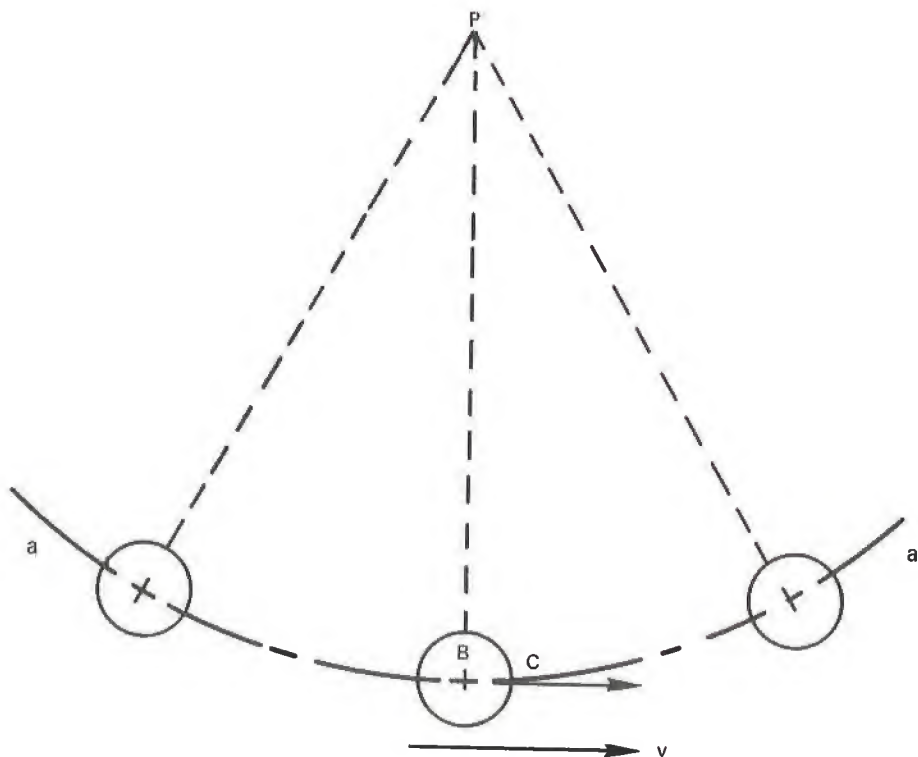


Fig. 13-1 A Small Force Applied at Proper Intervals Will Cause Resonance

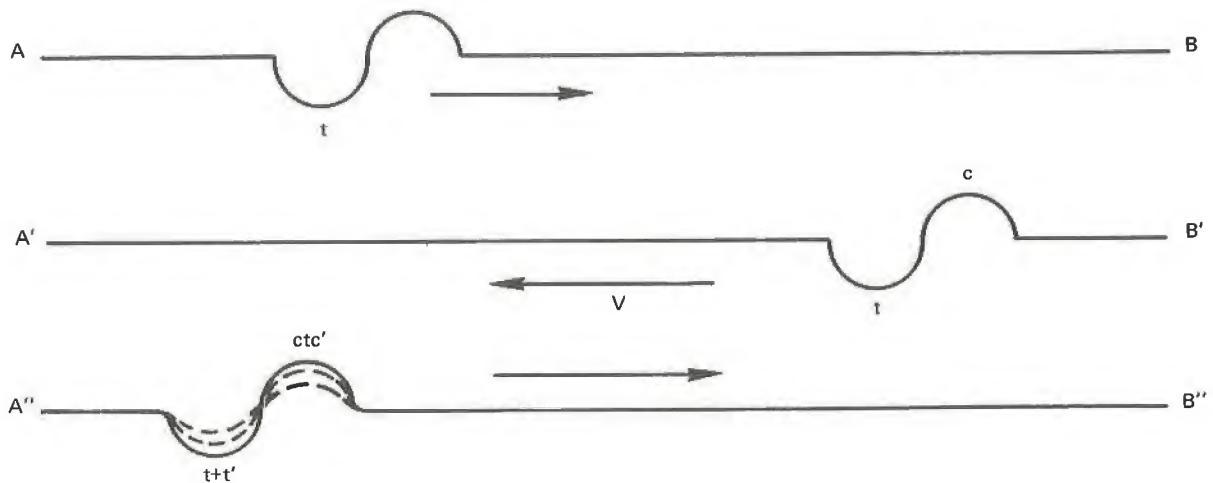


Fig. 13-2 Resonance in a Stretched String Producing a Wave of Large Amplitude

Most musical instruments such as the organ, the clarinet, even the human voice, depend on vibrating air cavities to produce their particular sound. The tones produced by such devices are amplified and enriched by resonance.

In process control, instrumentation, and fluid flow systems, resonance often occurs and is sometimes unwelcome.

Let us look at resonance in a pipe. Resonance in a pipe is much like resonance of a stretched string. The waves in the pipe, of course, are *compressional* rather than *transverse*, since a gas transmits only compressional waves. Let us take a look at a wave on a string fixed at both ends. In string AB of figure 13-2 a single transverse wave is traveling toward the right with a velocity V . The wave is reflected at the end B where the string is held fixed. The wave returns along the string as shown in A'B' with the trough preceding the crest. It will continue this back-and-forth motion until its energy is dissipated. A large amplitude will be built up in the string when an alternating force of small amplitude and the right period

are applied. Let the applied force have a frequency, f , and a period, T . Then resonance will occur when

$$VT = 2L \quad (13.1)$$

where L is the length of string. This condition is true because the front of a crest leaving A at the beginning of time T will have returned as the front of a trough at the end of that time. Then we may write $VT = V/f = 2L$,

$$V = 2Lf \quad (13.2)$$

but V is also equal to $f\lambda$, and

$$\lambda = 2L \quad (13.3)$$

This equation indicates that the length of the string equals one-half the wave length.

In the case of a pipe, closed at one end, the waves are totally reflected in such a way that a condensation (crest) or a rarefaction (trough) is returned as a condensation or a rarefaction. When the pipe end is open, condensations return as rarefactions and rarefactions return as condensations. This relationship is an important factor in deter-

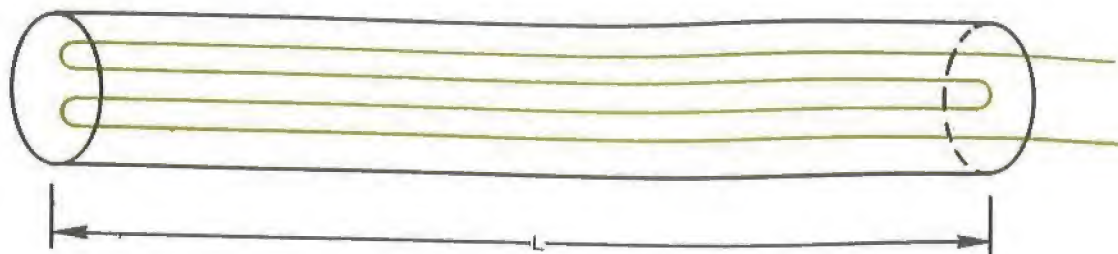


Fig. 13-3 Resonance in an Open Pipe

mining at what frequency a pipe or air column will resonate. If pipe of length L is open at each end as shown in figure 13-3, then condensation c enters at one end and returns as a rarefaction r . The rarefaction returns to the other end and leaves as a condensation because the pipe is open at both ends. The lowest frequency at which the pipe will resonate is found by

$$VT = 2L$$

where T is the time between entrances of condensation into the pipe.

Since T equals $1/f$

$$f = V/2L \quad (13.4)$$

or

if the frequency increases, resonance will occur whenever

$$f = nV/2L \quad (13.5)$$

where n is a whole number.

For the purposes of this experiment we will use the fundamental equation of wave motion

$$V = f\lambda$$

to determine the velocity of sound in air.

If a vibrating source (such as a tuning fork) is held over an air column in a closed tube, as shown in figure 13-4, compressions and rarefactions will travel down the tube and be reflected. If the tube length is adjusted until it is equal to exactly one-fourth the wave length of the tone from the fork, the returning wave will arrive back at the top of the tube precisely in phase with the next vibration of the fork, and a tone of unusually loud volume

will be heard. This observable fact is known as resonance, and it occurs when standing waves are set up in the tube with a node at the closed end and antinode very near the open end. This situation can occur when the length of the tube is any odd number of quarter wave lengths of the sound waves being emitted by the fork. Resonance will occur when

$$L = \frac{\lambda}{4}, \frac{3\lambda}{4}, \frac{5\lambda}{4}, \text{ etc.} \quad (13.6)$$

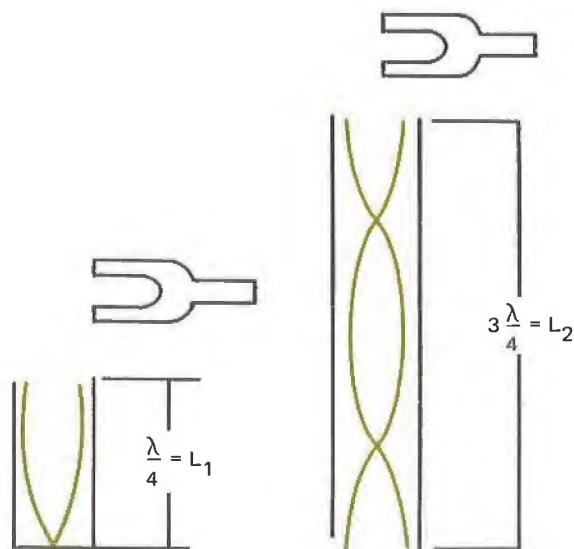


Fig. 13-4 Diagram Showing Relationship Between Wave Length of Sound and Distance to First and Second Points of Resonance

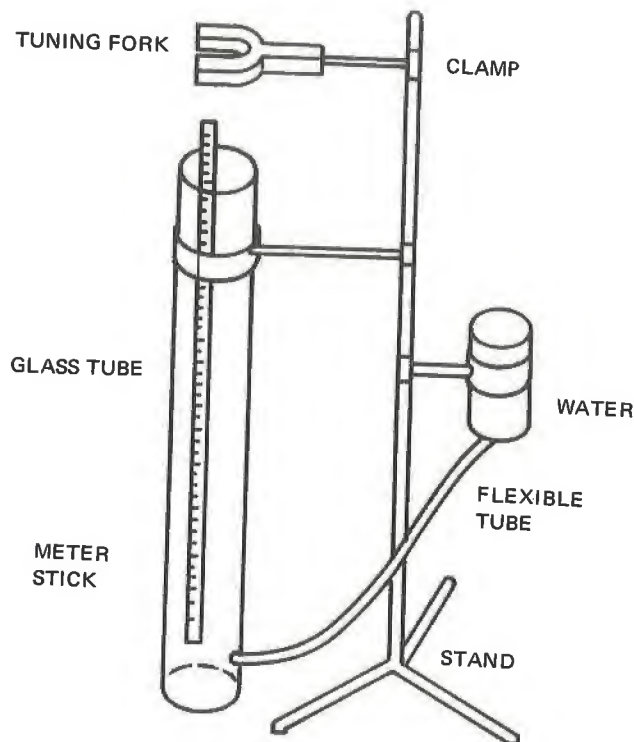


Fig. 13-5 Resonance Tube Apparatus

The apparatus used in the experiment consists of a glass tube about 4-ft long and 1-in. inside diameter fitted with a rubber stopper and tubing connection to a water reservoir whose level can be changed to make the water rise or fall in the tube itself as shown in figure 13-5.

Since the frequency of the fork is given by the manufacturer and λ can be calculated from measurements taken at points of resonance, the velocity of sound in air may be calculated from the equation, $V = f\lambda$.

MATERIALS

- | | |
|---|---|
| 1 Glass tube, 1-in. diameter, 48-in. long | 3 Lab stand clamps |
| 1 One-hole rubber stopper | 3 Tuning forks 384, 426 $\frac{2}{3}$, and 512 frequencies |
| 1 Water reservoir | Rubber hammer |
| Rubber tubing | Meter Stick |

PROCEDURE

1. Set up the apparatus as shown in figure 13-5.
2. Raise the water level in the glass tube until it is near the top.

3. Position the tuning fork at the top of the glass tube so that it will barely clear the glass while vibrating.
4. Strike the tuning fork with a rubber hammer.
5. Lower the water level slowly until the first resonant point is reached. The sound will be quite loud at this point.
6. By approaching the resonance point carefully from above and below, determine its positions as accurately as you can.
7. Measure L_1 , the distance from the bottom bar of the fork to the first point of resonance.
8. Repeat steps 4, 5, and 6 to determine L_2 and L_3 .
9. Repeat the entire process with each of the other forks.
10. Record the frequencies of the forks in the data table (figure 13-6).

Trial	Frequency	$L_1 = \lambda/4$, ft.	$L_2 = 3\lambda/4$, ft.	$L_3 = 5\lambda/4$, ft.
1				
2				
3				

Fig. 13-6 The Data Table

ANALYSIS GUIDE. Write a paragraph explaining your observation of resonance. What are the necessary and sufficient conditions for resonance? Calculate your error of measurement in each case.

PROBLEMS

1. From the measurements taken with the resonance tube, calculate values for velocity of sound in air for each of the three tuning forks.
2. From the measurements taken, determine the period of each fork.

experiment 14 SOUND WAVES IN A SOLID

INTRODUCTION. While resonant effects may be useful in many cases, there are times when they are quite undesirable. In this experiment we will examine the phenomenon of resonance and measure the velocity of sound in a solid.

DISCUSSION. The relatively large increase of the amplitude of a vibration produced by applying a small periodic force at prescribed intervals is known as resonance. Resonance may occur in almost any physical system capable of full vibrations. Perhaps the best way to illustrate the concept of resonance is to review an example given in the preceding experiment.

Suppose a ball is suspended by a wire from a point and a light-thread is attached to the

ball as shown in figure 14-1. By itself it is a pendulum and can oscillate with a definite period. The tiny force that the thread can exert without breaking will displace the ball only a very small distance. When the force is removed, the ball swings back to the left beyond its rest position. If the force is again applied while the ball is going to the right, the ball will attain a second displacement slightly greater than the first one. This is an example of mechanical resonance.

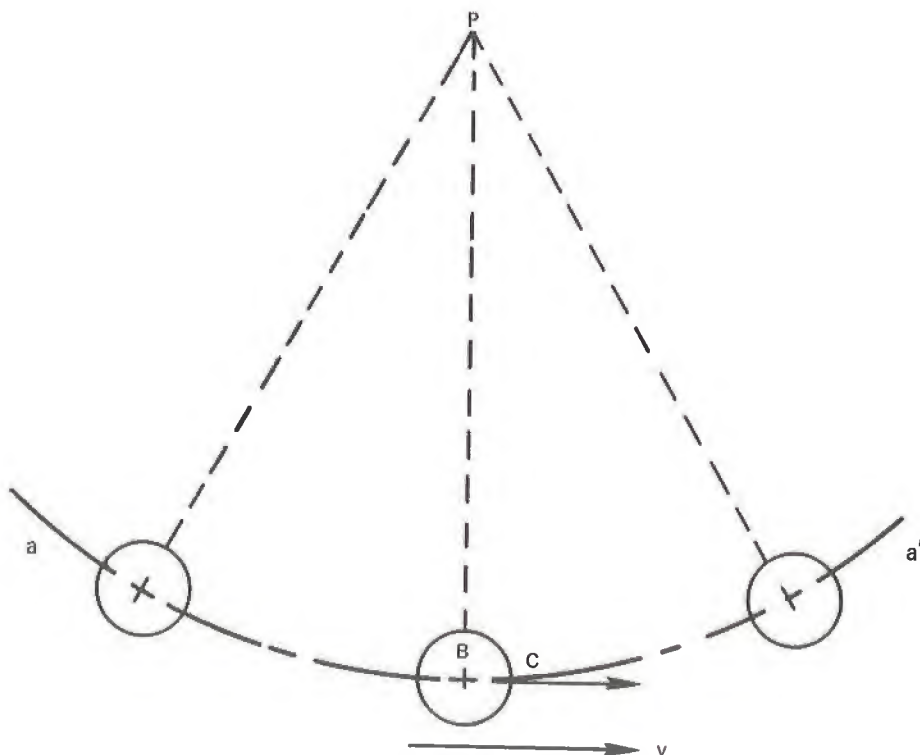


Fig. 14-1 A Small Force f Applied at Proper Intervals Will Cause Resonance

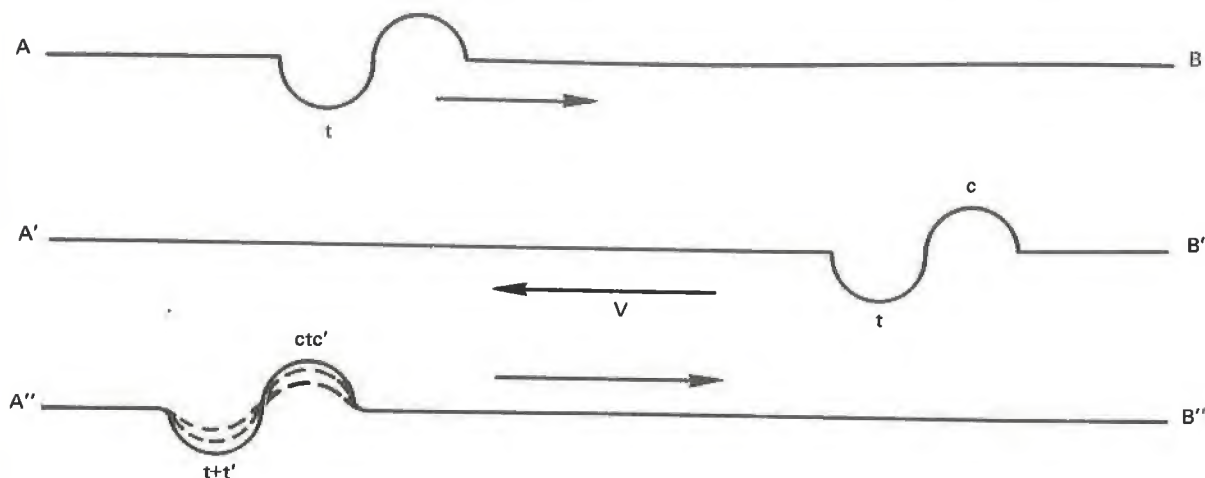


Fig. 14-2 Resonance in a Stretched String Producing a Wave of Large Amplitude

Many musical instruments such as an organ, or a clarinet, depend on vibrating air cavities to produce their particular sound. Their tones are amplified and enriched by resonance.

In process control, instrumentation, and fluid flow systems, resonance can occur and is sometimes unwelcome.

The vibration of an open pipe is much like the vibrations of a stretched string. The waves are longitudinal rather than transverse, since a gas transmits only longitudinal waves. First let us take a look at the wave length of free vibration of a string. The string shown in figure 14-2 has a single transverse wave traveling toward the right with a velocity V . The wave is reflected at the end where the string is attached to an object. The wave returns along the string as shown in the second sketch, the trough preceeding the crest. It will continue this back-and-forth motion until its energy is dissipated. A large vibratory amplitude will build up on the string when a periodic force of small amplitude and the right frequency is applied. Let the applied force have a frequency f and a period T . Then resonance will

occur when

$$VT = 2L \quad (14.1)$$

where L is the length of string. This condition is true because the front of a crest leaving A at the beginning of time T will have returned as the front of a trough at the end of that time. Then we may write $VT = V/f = 2L$, or

$$V = 2Lf \quad (14.2)$$

but V is also equal to $f\lambda$, and

$$\lambda = 2L \quad (14.3)$$

This equation indicates that the length of the string equals one-half the wave length of the vibration.

In the case of a vibration traveling in a pipe, on approaching a more dense medium, the waves are reflected in such a way that a condensation or a rarefaction is returned as a condensation or a rarefaction. When the medium is less dense, condensations return as rarefactions and rarefactions return as condensations. This relationship is important

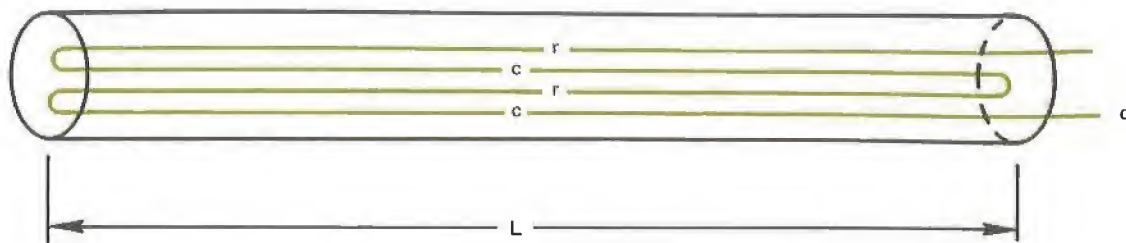


Fig. 14-3 Resonance in an Open Pipe

in determining the resonant frequency of a pipe or air column. Suppose we have a pipe of length L which is open at each end as shown in figure 14-3. A condensation c enters at one end and returns as a condensation because the pipe is open at both ends. The lowest frequency at which the pipe will resonate is found by

$$VT = 2L$$

where T is the time between the entrance of successive condensations into the pipe.

Since T equals $1/f$

$$f = V/2L \quad (14.4)$$

or if the frequency increases, resonance will occur when

$$f = n V/2L \quad (14.5)$$

where n can be any whole number.

For the pipe closed at one end in figure 14-4, the reflection at the closed end occurs with a change in phase of 180° . In this case the fundamental frequency will be

$$f = V/4L \quad (14.6)$$

The wave in a close-ended pipe must always have a particle velocity node at the closed end and a loop at the open end. Consequently, the closed pipe will sustain only odd numbered harmonics. The equation for the resonant frequencies of the pipe closed at one end is

$$f = n V/4L$$

where n must have the values of 1, 3, 5, 7, etc.

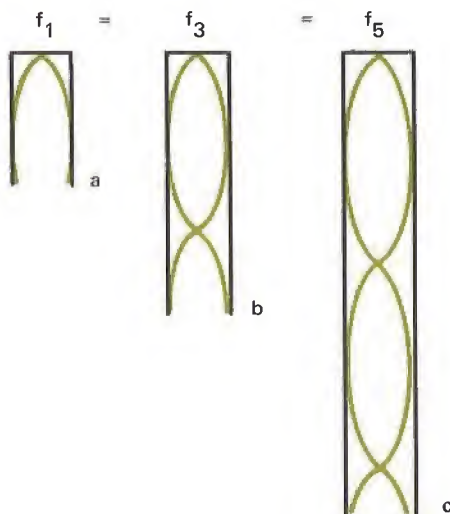


Fig. 14-4 Closed Pipes with Odd Numbered Harmonics

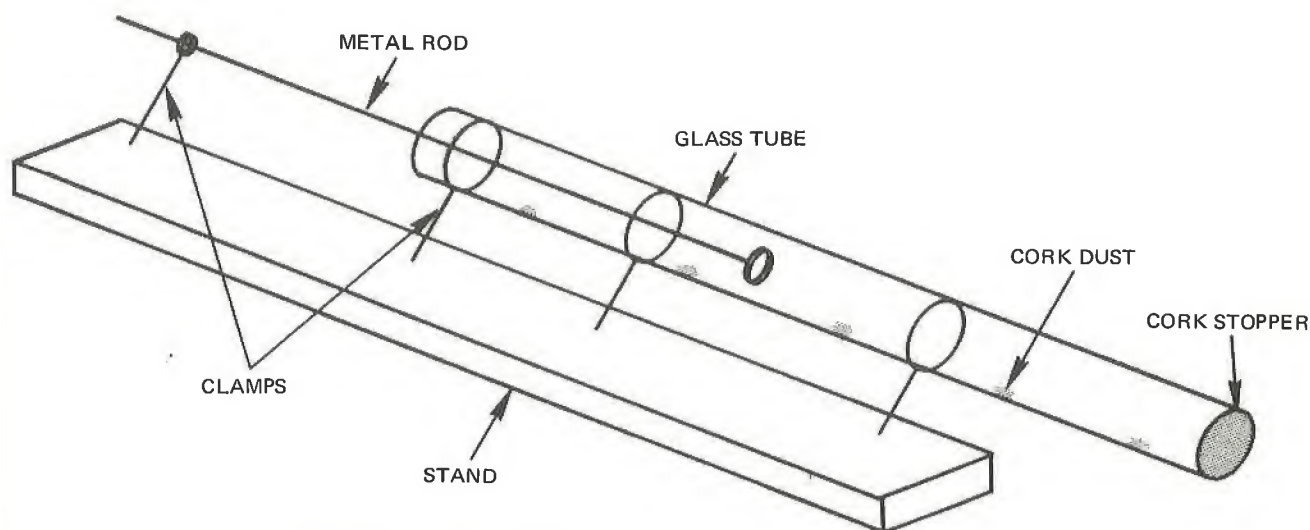


Fig. 14-5 Kundt's Tube Apparatus for Measuring the Velocity of Sound in Metal Rods by Resonance

In this experiment we will examine resonance by setting up waves in the air inside a glass tube. These waves are created by longitudinal vibrations in a metal rod which is positioned inside the glass tube as shown in figure 14-5.

The location of the stationary waves in the air may be figured out from what happens to the cork dust as the air in the tube vibrates in resonance with the natural vibration frequency of the metal rod. The rod is stroked with a rosin or woolen cloth to set up vibrations. There may be a variety of cork dust patterns, but regardless of the shape of the

particular pattern, the distance between corresponding points of adjoining patterns will be one-half a wave length as shown in figure 14-6.

Since the air is forced to vibrate in resonance with the rod, the frequencies are the same. From the basic wave equation we have

$$V_r = f\lambda_r \quad \text{and} \quad V_a = f\lambda_a$$

$$\text{Dividing,} \quad \frac{V_r}{V_a} = \frac{f\lambda_r}{f\lambda_a} \quad \text{or} \quad V_r = V_a \frac{\lambda_r}{\lambda_a}$$

If the rod is clamped at the midpoint, making a node, and has antinodes at either end

$$\lambda_r = 2L$$

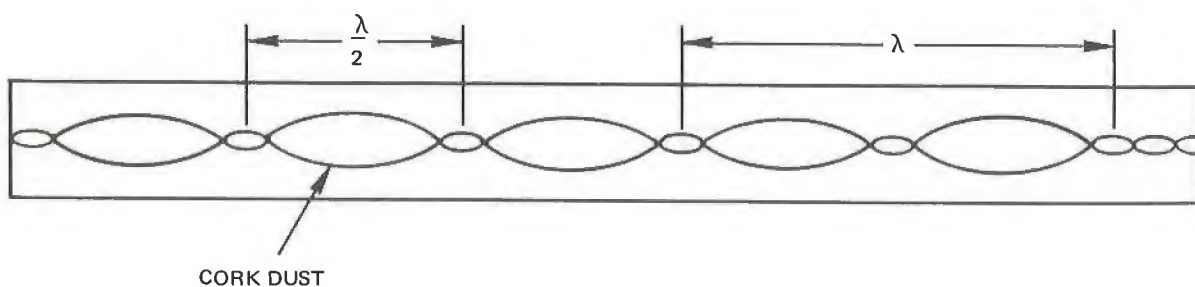


Fig. 14-6 Cork Dust Pattern Obtained by Resonance

Finally $V_r = V_a \frac{2L}{\lambda_a}$

where

V_a = velocity of sound in air, fPS

V_r = velocity of sound in metal rod, FPS

λ_a = wave length of sound in air, ft.

λ_r = wave length of sound in the rod, ft.

L = length of the rod, ft.

The velocity of sound in air (in fPS) may be calculated from

$$V_a = 1,087 \pm 1.1T \quad \text{fPS}$$

where T is the number of degrees above or below 32°F . The velocity of sound increases with rising temperature.

MATERIALS

- | | |
|---------------------------------|----------------|
| 1 Glass tube approx. 4 ft. long | 1 Woolen cloth |
| 2 Metal rods (Brass and Steel) | 1 Meter stick |
| Cork dust | 1 Thermometer |
| Rosin | 1 Stopper |
| 1 Chamois skin | |

PROCEDURE

1. Insert the disc end of one metal rod into the glass tube.
2. Clamp the metal rod at its exact midpoint as shown in figure 14-5.
3. Put enough cork dust in the glass tube to lightly cover the bottom of the curved surface of the tube.
4. Put a stopper in the other end of the glass tube.
5. The clamps may have to be readjusted later for better resonance effect.
6. Stroke the free end of the metal rod slowly but firmly with the rosin cloth.
7. The glass tube may have to be adjusted for better resonance.
8. Do not measure the end half-waves.
9. Measure the distance of the maximum number of dust patterns.
10. Divide by the number of patterns to get the average of $\lambda/2$.
11. Scatter the cork dust.

12. Repeat steps 6 through 10 a second and third time.
13. Repeat the entire process with a rod of different material.
14. Measure the temperature of the room.
15. Measure the length of the rods used.

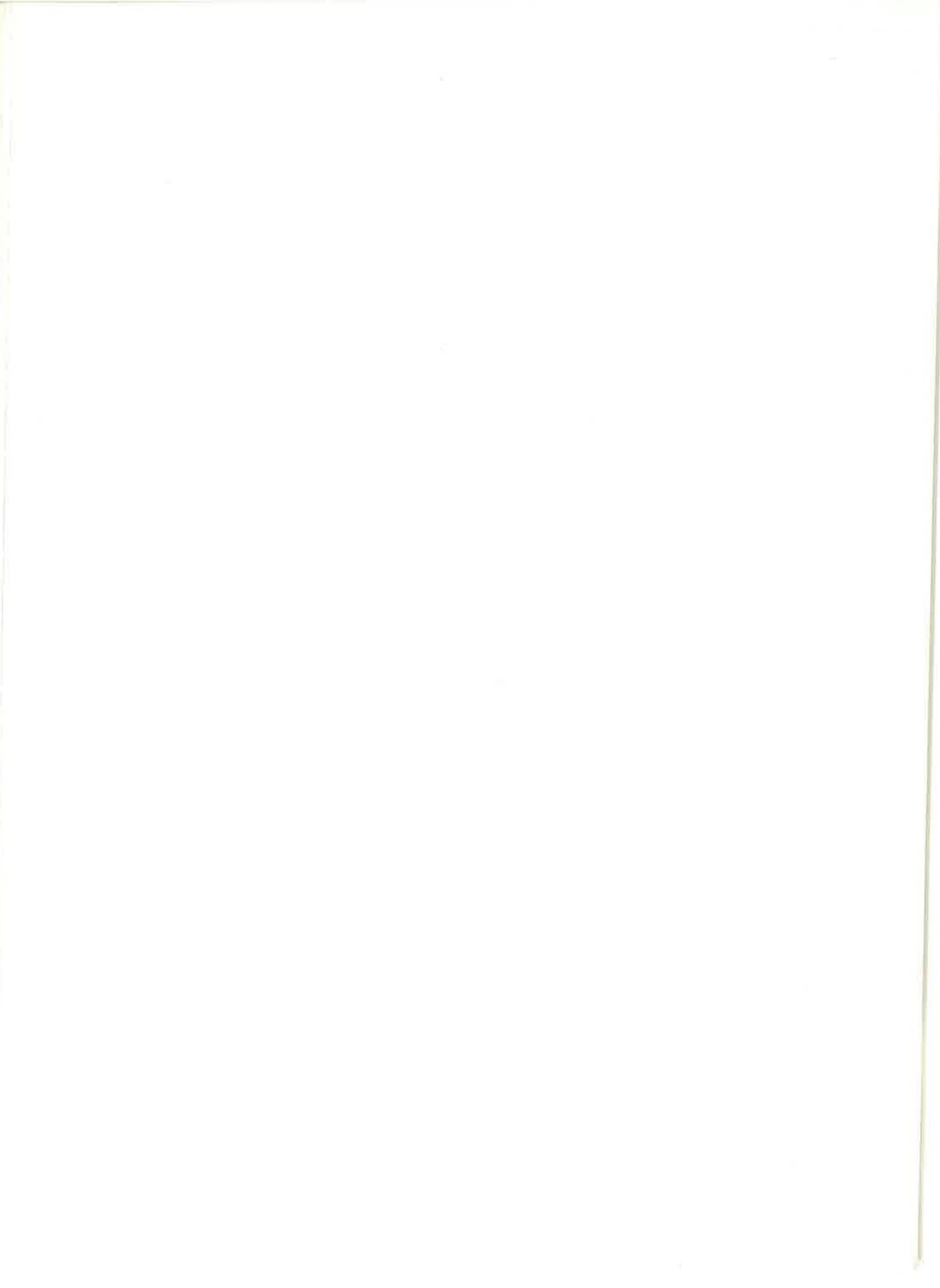
KIND OF ROD	TRIAL	DISTANCE OF CORK DUST PATTERN	NUMBER OF CORK DUST PATTERNS	LENGTH OF HALF WAVE $\lambda/2$, Ft
	1			
	2			
	3			
	1			
	2			
	3			

Fig. 14-7 The Data Table: Velocity of Sound in Metal Rods by the Resonance Method

ANALYSIS GUIDE. Write a paragraph explaining your interpretation of the things observed related to resonance in the metal rods. What are the conditions for resonance in a metal rod? Could resonance occur in a metal pipe?

PROBLEMS

1. Using the equations in the experiment, calculate the velocity of sound in the metal rods.
2. Given $\lambda_a = 0.125$ ft Find V_a
 $L = 3$ ft
 $V_r = 1150$ fPS



FLUID POWER SYMBOLS

	Main Line Conductor
	Pilot Line For Control
	Drain Line
	Enclosure Outline
	Instrument Line for Indicator, Recorder or Sensor
	Crossing Lines
	Joining Lines
	Hydraulic Flow Direction
	Pneumatic Flow Direction
	Line with Fixed Restriction
	Line Flexible
	Plugged Part
	Quick Disconnect Single Check
	Disconnect Double Check
	Reservoir Below Fluid Level Connecting Line
	Reservoir Above Fluid Level Connecting Line
	Filter Strainer



**Hydraulic Pump Fixed Displacement
Unidirectional**



**Hydraulic Pump Variable
Displacement Unidirectional**



**Hydraulic Motor Fixed Displacement
Unidirectional**



**Hydraulic Motor Fixed Displacement
Bi-directional**



**Hydraulic Pump - Motor Operating
in One Direction as a Pump. Operate
in Other Direction as a Motor.**



Pressure Gauge



Totalizing Flow Meter



Flow Meter



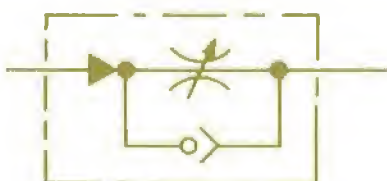
Temperature



Check Valve



Adjustable Flow Control Valve



**Adjustable Flow Control Valve
with Integral Check**

**Relief Valve Adjustable****Two-Way Valve Normally Open****Two-Way Valve Normally Closed
Infinite Position****Four-Way Valve - Two Position
Pilot Operated****Three-Way Valves Two Position
Mechanically Actuated Normally
Open****Three-Way Valve Two Position
Mechanically Actuated Normally
Closed****Four-Way Valve - Tandem Center
Three Position Manual Operated****Four-Way Valve - Closed Center
Three Position Manual Operated****Double Acting Cylinder Single
End Rod****Single Acting Cylinder Single
End Rod****Accumulator, Gas Charged**

LABORATORY REPORT WRITING

There are a number of different forms that a technical laboratory report may take. The forms proposed here are intended to meet the needs of these experiments and should not be considered to be universally applicable.

I. THE INFORMAL REPORT. In reporting the results of these experiments, it may be convenient to write an informal type of laboratory report. Informal reports are normally due at the start of the laboratory period following the period during which the experiment was performed. A report outline which you may wish to follow is given below.

- A. Cover Page.** The cover page should include:
 - 1. Your name.
 - 2. Your partner's name.
 - 3. Date the experiment was performed.
 - 4. Experiment title and number.
- B. Data Section.** The data section should include:
 - 1. A neat drawing of the experiment setup.
 - 2. A list of equipment used, including the manufacturer's name, model number, and serial number.
 - 3. Measured and calculated data in tabular form.
 - 4. Curves.
- C. Analysis Section.** The analysis section should contain a satisfactory technical discussion of the data. It should, in general, include brief discussions of each of the points mentioned in the "Analysis Guide" and the solutions to any problems given at the end of the experiment.

II. THE FORMAL REPORT. You may be required to write and submit a formal laboratory report on some of the experiments that you have performed. All formal reports should be submitted in a satisfactory report folder, and are normally due about 1 week after the time that the experiment was performed. The formal report should include the following:

- A. Title Page.** The title page should contain the following:
 - 1. Title of the experiment.
 - 2. Name of the person making the report.
 - 3. Date the experiment was performed.
- B. Introduction Section.** The introduction should consist of a paragraph which sets forth the technical objective of the experiment.
- C. Theory Section.** The theory section should include a brief discussion of the theory which is pertinent to the particular experiment.

- D. Method of Investigation Section.** The method of investigation should include the following:
1. A neat drawing of the experimental setup.
 2. A brief outline of the experimental procedure.
 3. A brief outline of the calculations to be made.
 4. A brief discussion of how the calculations and measurements are to be compared.
- E. Equipment List.** The equipment list should contain every item of equipment used. It should show the manufacturer's name, the model number, and the serial number of every item.
- F. Data Section.** The data section should include a smooth copy of the following:
1. All measured values in tabular form.
 2. All computed values in tabular form.
 3. All curves.
- G. Sample Computations Section.** This section should include a smooth sample of each type of calculation made.
- H. Analysis Section.** The analysis section should include a discussion of each of the following points:
1. How valid is the data?
 2. What are the probable sources of error?
 3. What are the probable magnitudes of the different errors?
 4. How could the errors be reduced?
- I. Rough Data Section.** This section is provided to contain all work not presented elsewhere in the report. It should contain such items as:
1. Notes taken from reference material.
 2. The actual calculations performed.
 3. The actual rough experimental data.

As you have no doubt already concluded, the writing of a formal laboratory report is by no means quick or easy. You should remember however that a technician is frequently judged on the quality of his reports. Therefore, it is wise to make each report as good as possible.

EXPERIMENT 1 _____ Name _____
 Date: _____ Class _____ Instructor _____

COMPONENT	PRESSURE	FLOW RATE	RESISTANCE
25 ft Hose (1/4")			
1 ft Hose (1/4")			
Quick connection			
Relief Valve			
Check Valve			
Pressure Gauge			
Flow meter			
RESISTANCE VALUES			
1/4" Hydraulic Hose per foot			
Quick connection			
Relief valve			
Check valve			
Pressure gauge			
Flow meter			
CALCULATIONS			
$\text{Resistance} = \frac{\text{Pressure Diff.}}{\text{Flow rate}} \quad \text{in units of } \frac{\text{psi}}{\text{gal/min}}$			

Fig. 1-5 Data Table

EXPERIMENT 2 _____ Name _____
 Date: _____ Class _____ Instructor _____

		PRESSURE	FLOW RATE	RESISTANCE	CALCULATIONS
Circuit One (flow meter)					
Circuit One (measured)					
Circuit Two Part One	A				
	B				
	Total				
Circuit Two Part Two	A				
	B				
	Total				
Circuit Two - measured					

Fig. 2-7 The Data Table

EXPERIMENT 3

Date: _____

Name _____

Class _____ Instructor _____

BRANCH	PRESSURE	FLOW RATE	RESISTANCE	FLOW RATE VERSUS RPM					
				GPM	RPM	GPM	RPM	GPM	RPM
A				0.25		1.25		2.25	
B				0.50		1.50		2.50	
C				0.75		1.75		2.75	
Total				1.0		2.0		3.0	
Calculations									

Fig. 3-5 The Data Table

EXPERIMENT 4

Date: _____

Name _____

Class _____

Instructor _____

FLOW RATE	DIAMETER	LENGTH	PRESSURE	RESISTANCE
0.5				
0.6				
0.7				
0.8				
0.9				
1.0				
1.1				
1.2				
1.3				
1.4				
1.5				
1.6				
1.7				
1.8				
1.9				
2.0				

Fig. 4-4 The Data Table

EXPERIMENT 5

Name _____

Date: _____

Class _____

Instructor _____

	READING									
SAMPLE NO.	1	2	3	4	5	6	7	8	9	10
TIME IN SECONDS										
WATER LEVEL IN FEET										
FLOW RATE										

Fig. 5-3 Data Table

EXPERIMENT 6

Date: _____

Name _____

Class _____

Instructor _____

STEAM NO. 1

TIME-SEC	0	15	30	45	60	75	90	105	120	135	150	165	180
TEMP-°F													

ICE NO. 1

TIME-MIN	0	3	6	9	12	15	18	21	24	27	30	36	39	42	45
TEMP															

STEAM NO. 2

TIME-SEC	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	240	255	270
TEMP																		

ICE NO. 2

TIME-MIN	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
TEMP																					

Fig. 6-2 The Data Table

EXPERIMENT 7

Date: _____

Name _____

Class _____

Instructor _____

25 ft Hose No. 1	TIME (SEC)	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	
		PRESSURE PSI																	
25 ft Hose No. 2	TIME (SEC)	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	
		PRESSURE PSI																	
1 ft Hose	TIME (SEC)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	
		PRESSURE PSI																	

Fig. 7-3 Data Table

EXPERIMENT 8

Date: _____

Name _____

Class _____

Instructor _____

TIME (SEC)	0	20	40	60	80	100	120	140
PRESSURE PSI								
TIME (SEC)	160	180	200	220	240	260	280	300
PRESSURE PSI								

Fig. 8-2 Time-Pressure Table

TIME (SEC)	0	20	40	60	80	100	120	140	160
PRESSURE PSI									
TIME (SEC)	180	200	220	240	260	280	300	320	340
PRESSURE PSI									

Fig. 8-3 Time-Pressure Table

TIME (SEC)	0	20	40	60	80	100	120	140
PRESSURE PSI								
TIME (SEC)	160	180	200	220	240	260	280	300
PRESSURE PSI								

Fig. 8-5 Time-Pressure Table

TIME (SEC)	0	20	40	60	80	100	120	140	160
PRESSURE PSI									
TIME (SEC)	180	200	220	240	260	280	300	320	340
PRESSURE PSI									

Fig. 8-6 Time-Pressure Table

EXPERIMENT 9

Name _____

Date: _____

Class _____

Instructor _____

NO LOAD SETTING									
PRESS. A	FLOW RATE	PRESSURE A	PRESSURE B	FLOW RATE	POWER IN	RPM	FORCE IN POUNDS	POWER OUT	MOTOR EFF
100	1								
150	1								
200	1								
250	1								
300	1								

200	1.5								
200	2.0								
200	2.5								
200	3.0								

Pressure drop due to motor resistance with no load.

Fig. 9-3 The Data Table

EXPERIMENT 10 _____ Name _____
Date: _____ Class _____ Instructor _____

PRESSURE PSI	FLOW	CALCULATED ENERGY	MEASURED ENERGY
100			
200			
300			

Fig. 10-4 The Data Table

EXPERIMENT 11

Name _____

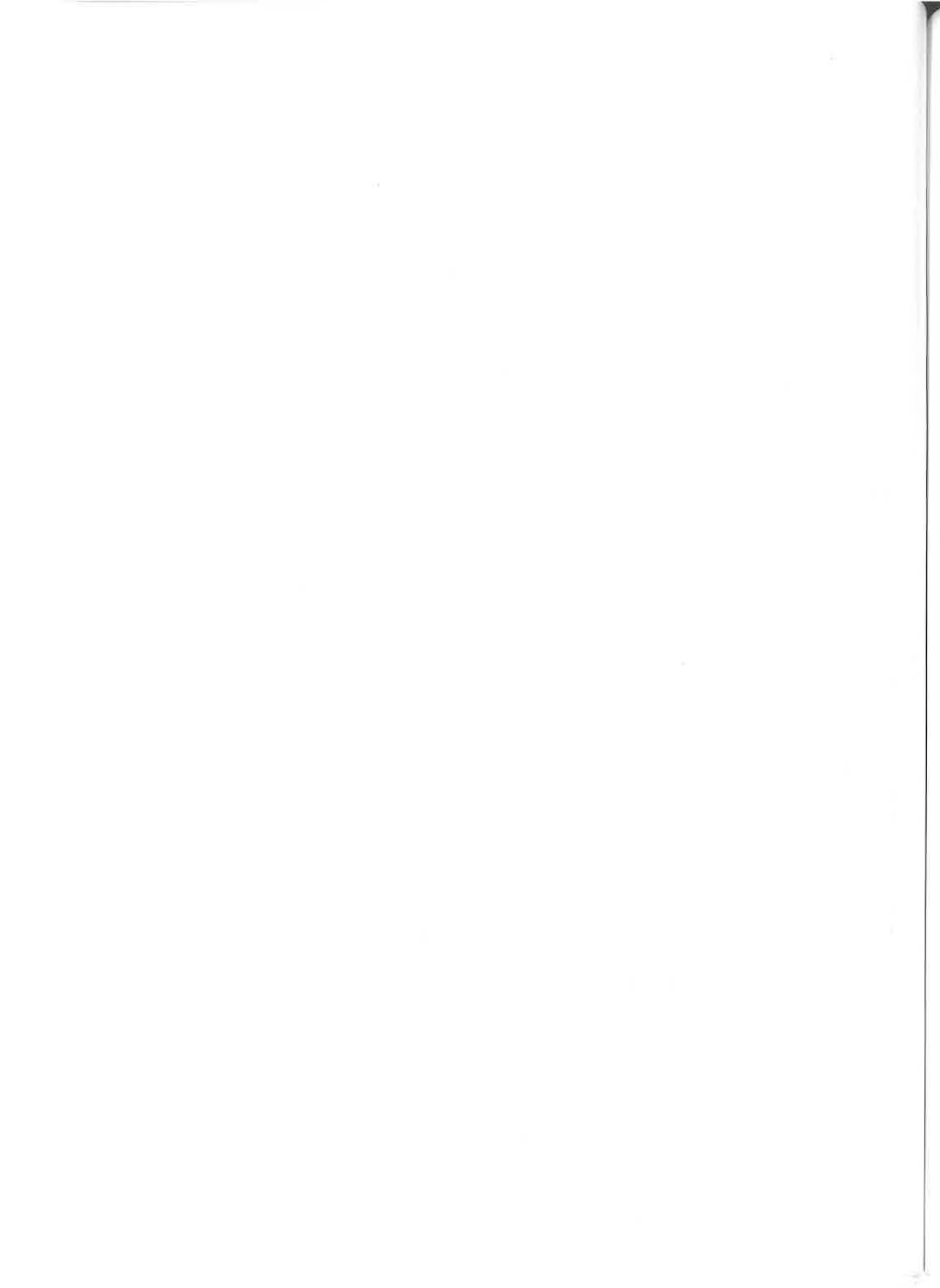
Date: _____

Class _____

Instructor _____

WEIGHT (lbs)	TIME (sec)	POWER (lb -ft/sec)
0		
5		
10		
15		
20		
25		
30		
35		
40		
45		
50		

Fig. 11-2 The Data Table



EXPERIMENT 12

Name _____

Date: _____

Class _____

Instructor _____

Initial Temperature of masses (T_1) _____					
	TIME				
MASS SIZE	1	2	3	AVERAGE	POWER REQUIRED (Q/t) (d)
$3/4 \times 3/4 \times 3/16$ in.					
$3/4 \times 3/4 \times 3/8$ in.					
$3/4 \times 3/4 \times 3/4$ in.					
$3/4 \times 3/4 \times 1\ 1/2$ in.					

Fig. 12-3 The Data Table

EXPERIMENT 13

Name _____

Date: _____

Class _____ Instructor _____

Trial	Frequency	$L_1 = \lambda/4$, ft.	$L_2 = 3\lambda/4$, ft.	$L_3 = 5\lambda/4$, ft.
1				
2				
3				

Fig. 13-6 The Data Table

EXPERIMENT 14

Name _____

Date: _____

Class _____ Instructor _____

KIND OF ROD	TRIAL	DISTANCE OF CORK DUST PATTERN	NUMBER OF CORK DUST PATTERNS	LENGTH OF HALF WAVE $\lambda/2$, Ft
	1			
	2			
	3			
	1			
	2			
	3			

Fig. 14-7 The Data Table: Velocity of Sound in Metal Rods by the Resonance Method



